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Effects of processing code on driving safety during simulated mobile phone use

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EFFECTS OF PROCESSING CODE ON DRIVING SAFETY DURING SIMULATED MOBILE PHONE USE

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ABSTRACT

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There is growing concern regarding the use of mobile communication devices while driving. Contemporary research indicates that there is indeed a negative impact on driver performance resulting from mobile phone use even among users of "hands-free" sets. Multiple resource theory is a common model for understanding human performance in multi-task domains and provides a framework for evaluating multi-task scenarios. The aim of this study is to investigate the effect of conversation processing codes upon driving performance. The potential conflict of conversations that require processing of visual information with the fundamental elements of the driving task was of primary interest. Thirty-two male and female participants of varying experience levels interacted with a PC driving simulation while engaging in a simulated hands-free phone conversation. The results indicate that driving performance while talking was significantly worse, and also that conversations requiring visuo-spatial processing caused the greatest interference with the driving task.

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INTRODUCTION

Mobile Phone Growth and Usage

There has been exponential growth within recent years in the mobile communications market. In particular, there has been increasing availability of mobile telephony to individuals. According to a recent report from the Cellular Telecommunications & Internet Association, the number of wireless subscribers has grown from 91,600 in 1985 to over 148 million as of June 2003 (CTIA, 2003). This increase in the presence of telephony has created a concurrent rise in dual task conditions. Individuals are talking on mobile phones in restaurants, while dealing with the cashier at the store, and even while driving their cars.

Of primary interest to this study is the use of mobile telephony while operating automobiles. The increase in simultaneously driving and speaking on mobile phones has been similar to that of the general increase in mobile telephony. The National Highway Traffic Safety Administration (NHTSA) found, in its research, that at any given time 3% of the nation's drivers of passenger vehicles are talking on a hand-held phone (Martin, 2001). A recent article in Consumers' Research stated that between 80% and 90% of mobile phone owners use their phone while driving at least some of the time (Ropeik, 2003). The article goes on to point out that, for certain regions of the country, drivers place from 40% to 70% of all mobile calls. An article by Hahn, Tetlock, and Burnett (2000) noted that cell phone owners admit that 60% of their phone usage occurs while driving. It is expected that such usage patterns will continue as the mobile telephony market expands further. Goodman, Tijerina, Bents, and Weirwille (2000) found additional evidence of the increase in mobile phone use among drivers. When they reviewed crash data from the Official Oklahoma Traffic Collision Report, they found a 15% increase in the number of mobile phones "in-use" during collisions between 1993 and 1994 (Goodman et al., 2000).

It has been somewhat difficult to discern the impact of mobile phone usage on driving safety, due to the fact that public accident data collection has been slow to track the potential role of mobile communications in accidents. Since mobile telephony is legal in most places, current police reporting strategies do not thoroughly investigate mobile phone usage as a active factor in accidents. However, several epidemiological studies (Violante & Marshall, 1996; Redelmeier & Tibshirani 1997; Laberge-Nadeau et al., 2003) have shown an association between mobile phone usage and automotive accidents.

LITERATURE REVIEW

Distraction and Driving

Accident data indicates that distracted drivers are a safety risk. Hendricks, Fell, and Freedman (1999) reviewed data from 723 accidents, and found that misperception and lack of attention were the causes more than 37% of the time. This finding is supported by a NHTSA report that driver inattention contributes to between 25% and 30% of accidents (Sundeen, 2002).

Distractions include a great many activities besides the use of mobile telephony. A recent AAA Foundation for Traffic safety study identified ten categories of distraction. They range from distractions external to the vehicle to such internal distracters as children, radios, vehicle controls, and mobile phones (Stutts et al., 2003). This AAA study also tracked the frequency of certain potentially distracting activities. As a result, many mobile phone proponents have positioned this study as a sign that phone use is not a safety concern, because many of the other potential distractions were observed with greater frequency. However, we must consider two specific limitations of the study. First, there was no comparison of mobile phone ownership among the participants as compared to the national average. If fewer participants owned them than was common throughout the country, the results are less significant. Even more important is the fact that the study did not measure in any way the impact of these "potential" distractions. So the focus of the AAA study was on the frequency and duration of "potentially" distracting activities, but it made no measurement or comparison of the level of distraction. The amount of interference a secondary task causes with the primary task, how much it degrades performance, is the critical safety issue and one that this study did not address.

Despite the possibility that other secondary activities may occur with greater frequency, the focus on mobile phone usage as a particularly hazardous distraction merits research regarding attention and driving. Howard and Connell (n.d.) describe driving as:

> "... a complex and difficult activity comprising a multiplicity of tasks. A little analysis suggests that drivers have to:
> * **manually control their vehicle**, this requires the coordinated use of both feet, and both hands,
> * **navigate their route**, a skill that is in itself complex and abstract,
> * **monitor the road and weather conditions,**
> * **take account of other road users' behavior**, and
> * **arrive at their destination on time.**"

Because driving is such a complex task with many components, activities that degrade attention while driving are particularly dangerous.

In fact, the Ford Motor Company considers distraction so significant an issue that they have invested $10 million in a virtual test center, in order to investigate the impact of various handheld and in-dash technologies (Kerwin, 2003). Ford has conducted a great deal of research on drivers, of various ages, interacting with technology ranging from mobile phones to DVD players. Ford has made one conclusive recommendation as a result of their research: novice drivers should not be allowed to use mobile phones while driving (Kerwin, 2003).

Introduction to Driving/Mobile Phone Research

A favorite topic of both research and legal debate is mobile phone use. It has become an item of popular debate, as individuals express aggravation with the newest "bad driver" issue. The topic moves further to the forefront with reports of phone-and-driving tragedies. Research has varied in its approach to the driving/phone-use scenario. Initial studies looked rather simply at the correlation between mobile phone use and driving performance.

These studies predominately perceived accidents or poor performance to be a consequence of peripheral distractions, such as holding the phone, dialing a number, or answering the phone. Indeed these actions might seem to fit the bill of primary source interference for the spatial task of driving. From the traditional perspective of multiple resource theory, these spatial tasks should create more interference with the driving task than an auditory task, like conversing. As a result, many believed that the use of a "hands free" device, in conjunction with mobile phones, would significantly reduce or eliminate the interference. Indeed, many groups, including mobile service providers and legislators, have advocated this approach.

However, additional research has cast great doubt on the effectiveness of such safety precautions. In particular, research by Strayer, Drews, and Johnston (2003) has demonstrated no significant difference in driving performance between individuals conversing on hands free devices and those using hand held phones. Matthews, Legg, and Charlton (2002) found that although there was an overall subjective difference between these phone types. Participants' subjective mental workload ratings were lowest for phones equipped with personal headsets, which demonstrated their belief that it was the easiest to use them while driving. However, driving performance was not found to differ between the different phone types despite the perception among participants that the phone with a headset was significantly easier.

Strayer and Johnston (2001) also investigated this dual task scenario and recorded interesting results. Their findings suggested that there is some aspect of the generative process of speech that interferes with driving ability. Another hypothesis is that the drving task and conversation task might utilize the same cognitive resources and create a demand greater than the available resources. This hypothesis is based on multiple resource theory and may explain the difference in performance. Multiple resource theory and its application to driving while using a mobile phone are discussed later in the paper.

Research into the interaction of mobile phone use and driving has been going on for some time now. In fact, Brown, Tickner, and Simmonds conducted one of the first studies in 1969. They investigated the impact of telephony on automobile use (Brown, Tickner, & Simmonds, 1969). During the last 15 years there has been an abundance of research conducted on the performance of drivers who use mobile communication devices. The level at which these investigations were conducted varied greatly. Researchers have pursued peripheral interference (effects of holding and manipulating the device) as well as attentional resources and cognitive loading as issues of interest.

Epidemiological Research

Investigation of the real world impact of mobile phone use on driving has occurred in several studies. Researchers have reviewed available statistics to determine what can be learned about the interaction of phone usage and automobile accidents.

Violanti and Marshall (1996) conducted one of the first epidemiological studies. They used a case-control design to evaluate the accident data from the state of New York. The authors investigated a random sample of drivers who had accidents during the span of 1992 to 1993. They used a mail survey to compare the driving behavior of these drivers with those of an accident free control group. Violanti and Marshall concluded that the more time a driver spent talking on a mobile phone while driving, the more likely they were to have an accident. In fact, their data showed a 5.59 fold increase in the likelihood of an accident among individuals who talked more than 50 minutes a month on phones while driving (Violanti & Marshall, 1996).

Redelmeier and Tibshiran (1997) reported an often cited statistical study in the New England Journal of Medicine. They evaluated 699 drivers who were involved in accidents and who had mobile telephones. The authors used detailed billing reports from each of the drivers and cross referenced that information with the details from each collision. Among their pool of drivers, Redelmeier and Tibshiran found a four fold increase in the likelihood of an accident while speaking on a mobile phone.

Laberge-Nadeau et al. (2003) conducted an epidemiological study in Canada regarding the growing use of mobile phone use while driving in that country. They compiled more than 36,000 questionnaires from drivers who owned mobile phones and combined this data with information from four wireless service providers as well as government crash data. Their research found a 38% increase in the risk of collision, involving injuries, among drivers who used mobile phones.

These studies showed a significant relationship between mobile phone use and automobile accidents. While this does not demonstrate causality, it further supports the case that phone use poses a serious challenge to the driving task. The nature of the relationship between mobile phone usage and driving performance requires specific and controlled investigation in order to understand it more fully.

Hand Held Versus Hands Free Phone Use

The primary concern to most casual observers is the expected motor control difficulties that arise from steering an automobile while holding and dialing the phone. Serafin, Wen, Paelke, and Green (1993) compared various levels of conversations with both hands free and manual call placement while driving. Their investigation revealed that manual dialing resulted in the greatest decrement to driving performance. The researchers also noted a connection between age and performance on the simulator. Their results indicated that younger drivers seemed to be less affected by the conversations.

Other studies have shown that there is little to be gained from voice dialing sets. Lamble, Kauranen, Laakso, and Summala (1999) found a significant increase in braking response time under the dual task condition of driving and phone use. The decrement persisted during a cognitive conversation task, in both the conditions of manually dialing and using a hands free device.

Matthews et al. (2002) also considered the impact of peripheral tasks in their comparison of hand held phones, speaker phones, and phones with headsets. Using a NASA-task load index, they found a significant increase in total workload for all three phone types relative to driving without using a phone. In fact, there was no significant difference in user experience, among any of the phones in over half of the incremental performance metrics.

Abdel-Aty (2003) took another look at the differences in driving performance resulting from hand held verses hands free phones. What is particularly interesting is that their study recorded the number of driver errors after the call was completed in addition to errors committed before and during the call. The results indicated that there was a significant increase in driver errors between no phone use and mobile phone use, whether hand held or hands free. This difference in error commission was also present after calls were completed, with drivers committing roughly twice as many errors as before calls were placed. Surprisingly, the greatest number of errors was committed after drivers completed conversations on hands free sets.

These examinations of hand held versus hands free mobile usage seem to indicate that the peripheral task of holding the phone might not be the most important factor influencing the driving task. This observation calls into question the current legislative trend of restricting phone usage to hands free sets while driving. Many researchers have, therefore, moved on to investigate what might be the source of task interference beyond the manipulation of the mobile device.

Hands Free Phone Studies

Regardless of the conclusiveness of efforts to compare hand held versus hands free phone use, several studies have demonstrated that, even without peripheral elements, mobile conversations impair driver performance. Alm and Nilsson (1995) found important effects resulting from phone use during driving. Their study was designed to evaluate the impact of mobile conversations on driving performance across two age groups. They tested old (age > 60 years) and young (age < 60 years) drivers in a dual task condition of driving and talking to evaluate three driving metrics: reaction time, headway and lateral position. They measured reaction time by looking at the time to brake in response to the deceleration of a leading vehicle. They determined headway by the following distance from the vehicle in front of the test participant and their vehicle. Lateral position was a measure of lane position. They tested all subjects in a high fidelity driving simulator consisting of a wide angle screen, a mobile base with a vibration-generating system, temperature control, and sound system, capable of creating a very life like driving experience.

Experimenters used a working memory span task (Baddeley, Logie, Nimmo-Smith, and Brerefon, 1995) to simulate the conversation task. They randomized the various "events" that required subject responses to prevent anticipation errors. Young drivers under the dual task condition showed reaction time .56 seconds slower than the control group, while older drivers suffered a 1.46 second delay on average. Headway did not vary significantly between subjects of the experimental and control groups though there was a significant difference between age groups. Younger drivers tended to follow more closely than older drivers, but they found no difference in distance between those subjects talking on the phone and their peers in age. Furthermore, they registered no significant differences on the metric of lateral lane position.

In addition to these quantitative measures Alm and Nilsson (1995) used a NASA-RTLX survey to measure subjective work load. Participants in the experimental group demonstrated a consistently higher perception of workload. These results, combined with the driving performance metrics, demonstrated an important element of the potential safety issues. Drivers were significantly slower to respond to the deceleration of the lead car when using the hands free mobile phone. Furthermore, members of the experimental group acknowledged a perceived increase in cognitive work load. However, these individuals made no attempt to compensate for this increase in task demand. Those who used phones and those who did not kept similar following distances within age groups. Drivers who were engaging in mobile conversation, and were admittedly more challenged, failed to adopt any compensatory strategies. This echoes the results of Lesch and Hancock (2003) who found similar results among their female participants.

The interactions of these results support the hypothesis that there is a real decrease in attentional resources and driving performance, and therefore an increased accident risk, when individuals use mobile phones while operating automobiles. It is also interesting to note that the age effect Alm and Nilsson (1995) observed corroborates the results from the studies of Serafin et al. (1993) and McCarley et al. (2001) discussed earlier.

Studies have shown that the impact of phone conversations on driving performance influence more than just reaction times. The work of Recarte and Nunes (2000), McCarley et al. (2001), Harbluk and Noy (2002), and Strayer et al. (2003) established the detrimental impact of auditory tasks on visual scanning and attention.

These perceptual impairments presented clear challenges to the performance of the driving task.

Aspects of Conversation

Recent research has focused on parsing the conversation in an effort to determine what elements of the phone conversation contribute most to performance degradation. Strayer and Johnston (2001) discovered an interesting insight during their study "Driven to Distraction: Dual-Task Studies of Simulated Driving and Conversation on a Cellular Telephone." The initial aim of the study was to evaluate the impact of hand held versus hands free phone sets. Participants performed a pursuit tracking task, to simulate automobile navigation, while they operated in one of three conditions. One group of subjects used hand held phones, another used hands free sets, and a third control group listened to the radio during the dual-task condition. The tracking task required subjects to follow a moving target with a joystick controlled cursor. Additionally, the target flashed red or green at random intervals. Participants were to press a thumb operated "brake" button when ever the red stimulus was detected. The performance measures for the experiment were reaction time and probability of failing to detect the red flash.

The results of the peripheral task investigation were consistent with previous findings; both conditions of phone use resulted in significant decreases in performance for both the reaction time and stimulus detection tasks. However, there was not a significant difference between the performances of the two phone groups. The absence of difference between the two phone use conditions is consistent with the findings of Redelmeier and Tibshirani (1997). What the investigators found intriguing was the lack of impact caused by the dual-task condition of radio listening. There was not a significant increase in reaction time or the probability that participants would miss the signal. Strayer and Johnston (2001) found the possibility that a listening task might not negatively impact driving worth investigating further.

Because listening to a standard radio broadcast involves a mix of attending to speech and music, an additional control condition was run using listening to a book on tape as the secondary task. The design was to measure the effect of passively participating in a conversation as a listener. To ensure that participants were attending to the secondary task, they administered a listening comprehension test. They required a participant to score 90% or better for their data to be included in the analysis.

The results of this control condition were similar to the radio condition. There was no significant difference between single and dual-task conditions for either performance measure. This finding suggests that the interference with the driving task may be a result of the speaking portion of conversations as opposed to the listening component.

Strayer and Johnston (2001) proceeded to further investigate the source of interference generated by mobile phone use. Participants performed a modified version of the tracking task from the previous experiment. The new tracking task removed the red and green flashes, instead, had two levels of difficulty to simulate driving an easy or difficult course. Performance on the primary task was measured by root mean squared tracking error (RMST).

The experimental conditions involved a single-task (driving alone) and two dual-task conditions. One distraction task was verbal shadowing, conducted over a hands free set. Participants would listen to and repeat words spoken to them while they performed the tracking task at both easy and difficult levels. The second dual-task condition was a word generation task in which subjects had to speak a word that began with the same letter that ended the word they just heard.

Strayer and Johnston (2001) found that the shadowing task did not produce a significant performance difference from the single task condition in either the easy or difficult tracking tasks. The word generation task, however, showed a significant performance decrement in both conditions. As a result, Strayer and Johnston suggested that the "creative" process of conversation produces a diversion of attention away from the driving task.

The progression in research has shown that the potential for interference caused by mobile phone use stems from more than the structural elements of holding and manipulating the phone. This review suggested that there are issues of attention that arise from phone use while driving and that continued investigation of this area was warranted. In particular, a closer evaluation of how the various aspects of conversation affected the driving task would be insightful and interesting.

Guiding Psychological Theory

In order to consider the interaction of conversation and driving tasks at a deeper level, there must be some governing principle selected that can explain the cognitive interaction of the two tasks. Kantowitz and Knight (1976) originally proposed multiple-resource theory. Wickens (1991) and Wickens and Hollands (2000) elaborated on the theory and has repeatedly demonstrated its relevance to dual-task scenarios. Multiple-resource theory provides various stages at which the interaction of multiple task performance should be considered. The foundation for the multiple resource theory is Baddeley's working memory model. Baddeley's working memory model first identified the resource components described by the various multiple resource theorists.

Baddeley and Hitch (1974) first proposed the working memory model in response to the plethora of short term memory models that their contemporary colleagues were proposing. The authors believed that short term memory was integral to the more complex human reasoning capabilities. It was a significant departure from other theories of that time and its general tenants have persevered to today.

Baddeley (1999) related how he and Hitch developed the overall structure that was composed of three elements: a Central executive, a Visuo-spatial sketch pad, and an Articulatory loop (see Figure 1).

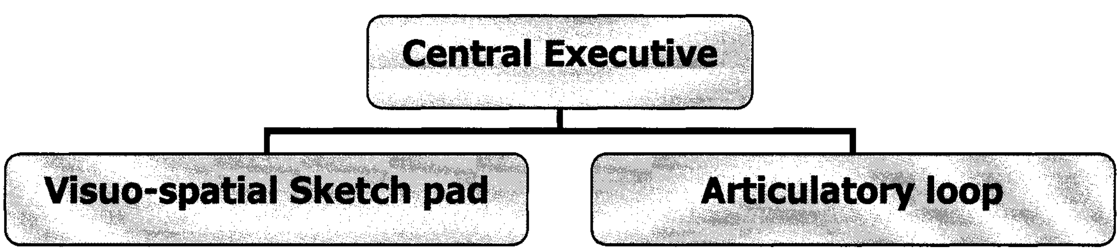

Figure 1. Diagram of Baddeley's working memory model.

The working memory model proposed that the Central executive was where the primary processing took place as well as the control of the two subcomponents. The two subsystems were used to assist in specific types of mental processes. The Visuo-spatial sketch pad was the component of short term memory that was responsible for manipulating and holding spatial information during processing. Alternatively, the Articulatory loop was the memory component used for language acquisition, articulatory rehearsal, and the short term storage of various bits of information. Thus, the working memory model of short term memory was one of divided memory. The Central executive exists with two dedicated memory resources, one for verbal/articulatory tasks and one for spatial.

The working memory model concept of limited processing resources is the foundation of multiple resource theory. Wickens (1991) identified the two dedicated short term memory resources as critical among the three distinct elements within the multiple resource model of dual task performance (see Figure 2).

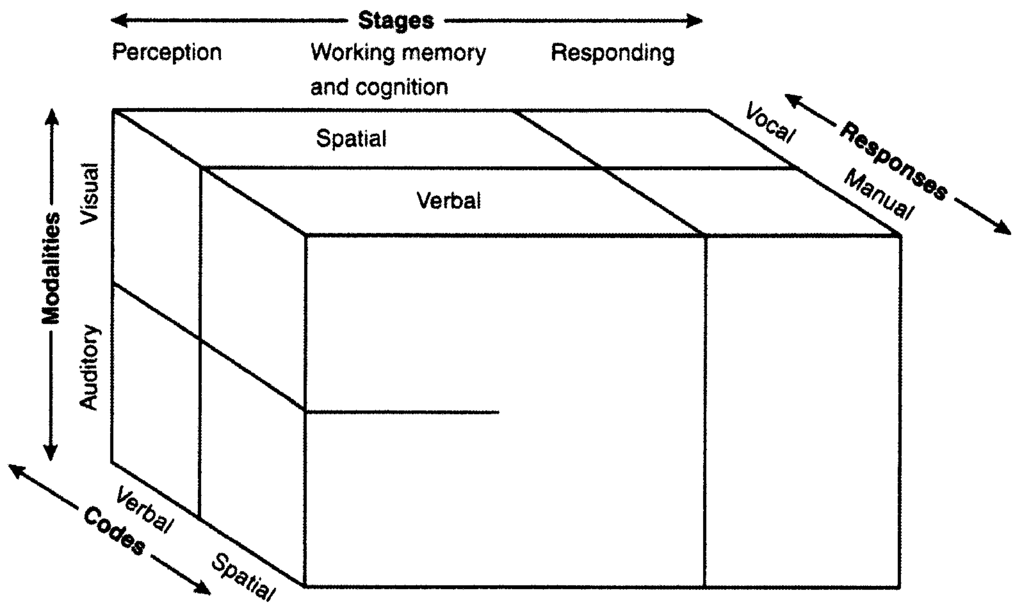

Figure 2. Three dimensional illustration of multiple resource theory dimensions. (From Wickens, C. D., & Hollands, J. G. (2000). *Engineering psychology and human performance*. Upper Saddle River, New Jersey: Prentice Hall. p. 449)

The first concept was that of processing stages. The processing stages were defined as those activities that pertained to perception, cognitive processing, and response (Wickens, 1991). Furthermore, separate visual and auditory resources were proposed to exist at each of these stages. The theory suggested that two tasks that were focused in different stages of processing would be more likely to be timeshared effectively. Driving and cell phone use each posed demands at both stages of processing and could be expected to produce some level of performance degradation.

The second dimension of multiple resource theory was the idea of code resources. The theory proposed that there are two separate resources for spatial and verbal information as outlined in the working memory model. These resources affected tasks by how the information was coded at the stage of perception, central processing, and response. It followed from this scheme that two tasks that utilized different codes at the various stages could be performed more effectively than tasks that shared resources at one level or another. Traditionally people considered driving and mobile phone use to require different resources. This stemmed from a shallow evaluation of the two tasks. Considering only the observable aspects of the two tasks, driving appeared to require visual perception resources, and phone use required auditory resources.

The modality of perception and response mechanisms are the initial and final processing stages of multiple resource theory. Modalities of perception are typically either visual or auditory. This dimension specifies how the information related to multiple tasks is encoded. Two tasks that require listening or two tasks that require watching will not be shared as well as one task that requires listening and another that depends upon a visual stimulus. Driving has its primary stimulus as visual and mobile phone conversations have an auditory input modality therefore they may be shared well from an input modality perspective.

Response mechanisms relate to the stimulus response a task requires. Typical task responses are either verbal or motor. Similar to input modalities two tasks that require a verbal response or two that require a motor response are more likely to conflict than one task with a verbal response and another with a motor response. Driving and mobile phone use are different at this stage of processing as well: driving required a manual response and phone use required a vocal response mechanism.

The middle stage of multiple resource theory is that of cognitive processing. At this stage the type of processing required by the task is considered. A process may require either visuo-spatial resources or articulatory resources. An initial consideration of the driving task with its primarily visual input and motor response and the mobile conversation task with its auditory input and verbal response might suggest that they should be shared well in light of multiple resource theory. However, if one examined these tasks at a processing code level, it would become apparent that, under certain conditions, they could both require spatial processing codes. For instance, sometimes the conversation required the individual to create and verbally describe mental images. This potential resource conflict during the cognitive processing stage could be a critical issue for the simultaneous performance of these two tasks. As a result the focus of this study was to examine the interaction of the type of processing codes associated with the various aspects of the concurrent tasks of driving and mobile phone use.

Driving and Conversing, the Cognitive Implications

What sets mobile phone use apart from other potential distractions is the especially powerful impact it may have on situation awareness and visual scanning. Several studies have investigated the impact of auditory tasks on visual scanning. Recarte and Nunes (2000) measured changes in participants' saccadic eye movements while driving in single and multi-task conditions. They investigated the impact of a conversation's processing code on eye movement. Recarte and Nunes required participants to drive four different road routes while performing either a verbal task or a spatial-imagery task. The verbal task was a word repetition task, participants repeated words spoken to them by an experimenter. The visual-imagery task required the generation of mental images and occasionally mental rotation of imagined objects. The authors measured five different variables of ocular behavior for each participant; pupil diameter, fixation duration, horizontal and vertical position in the field of view and finally variability of fixation and the two visual field coordinates for each condition.

The results indicated that when drivers performed either of the secondary tasks pupillary dilation increased, this was indicative of an increased cognitive load. The amount of dilation by task suggested that the work load for the verbal and spatial tasks was similar. However, the duration of fixation significantly increased during the visual-imagery task. This implied that while the cognitive load for both secondary tasks may have been similar, the effects varied by processing code. The review of fixation position data showed a significant reduction in the range of positions when participants performed a secondary task. This indicated that participants were looking systematically at less of the visual scene and that more fixations were centrally located. The visual-imagery task produced the smallest field of visual inspection, indicating that it had the greatest impact on visual perception. This was in keeping with multiple-resource theory that suggested that driving and mental imaging conflicted at the processing code level.

McCarley et al. (2001) evaluated the effect of naturalistic conversation on an individual's visual scanning of driving scenes. The experiment required participants to detect changes in complex traffic scenes while under single-task conditions or while carrying on a conversation with another participant. They presented participants with varying representations of traffic scenes. This presentation arrangement required an attentional search of the displays (Rensink, Oregan, & Clark, 1997) in order to detect change. The conversation task was carried out remotely with a hands free apparatus to simulate mobile phone use without peripheral sources of interference. They divided participants into two groups based on age, in order to examine interactions of age and multi-task degradation found in other research. The ability of participants to detect change and the time required to report observed changes were both recorded.

The results of the experiment uncovered significant differences in error and reaction times between young (mean age = 21.43) and old (mean age = 68.43) participants. old participants had a significantly higher mean error rate in the dual-task condition, 29.64% versus the single-task condition, 21.79%. Mean error rates for young participants did not vary significantly across conditions. Average reaction times between age groups were significantly different, with young observers performing more quickly. Times did not vary by task condition within age groups, however. In summary, these results suggested that the conversation caused an increase in errors but did not increase the time to detect changes that were identified.

The experimenters evaluated eye tracking data collected on the participants to further evaluate the observed changes in performance. They found that the number of fixations per trial increased for both age groups under the dual-task condition. It was, therefore, possible that the conversation was hampering the guidance and effectiveness of saccades.

The final evaluation was of the salience (magnitude) and meaningfulness (relevance) of the representational changes. A significant interaction was found between the number of fixations to detect meaningful changes between the old participants and task conditions. Old participants took significantly more fixations to detect highly meaningful changes when in the dual-task as opposed to single-task condition. Therefore, while conversation seemed to be of some general detriment to visual scanning, the greatest impact was on old drivers' ability to detect meaningful changes. This had important implications for practical scenarios. In such scenarios the ability to detect changes relevant to the driving task would have been critical to safety.

Harbluk and Noy (2002) also examined the effect of a conversation task on visual processes while driving. Participants in the study drove an 8 km road route under three different conditions: single task (no secondary task), dual task with a simple arithmetic conversation, and dual task with a complex arithmetic conversation. During the task performance eye tracking equipment was used to record participants' eye movements under the various conditions. All correspondence was carried out over a hands free phone set. Analysis of the eye tracking data found a significant reduction in the number of saccadic eye movements in the complex arithmetic condition. The data also indicated that while performing the more difficult math tasks, the time drivers spent looking directly ahead increased and monitoring of the surroundings decreased. This finding related well to the reduced situation awareness found in other studies (Parkes & Hooijmeijer 2000, Lesch & Hancock, 2003).

More alarming than the change in eye movement was the apparent decrease in the effectiveness of visual perception. Richard et al. (2002) investigated the impact of a concurrent auditory task on visual search performance. Participants in the study examined driving related scenes in an effort to identify changes. They performed the visual task as a single task and, concurrently, with an auditory task that required listening and responding to the experimenter. Researchers presented participants with photographs of traffic scenes and asked them to identify changes as they became apparent.

The results indicated a decrease in visual scanning performance in the concurrent auditory task condition. The length of time it took participants to notice changes in the visual scene increased significantly when performing the auditory task. This reduction in visual perception was called change blindness (Richard et al., 2002). The implications of dividing attention between auditory tasks and the visual scanning task in the driving environment were negative.

Strayer, et al. (2003) furthered the investigation of whether mobile phone use impaired visual perception in the driving environment. Rather than use a series of static images, as Richard et al. (2002) did, Strayer, Drews, and Johnston used a high fidelity driving simulator. They assessed participants' visual attention performance using an object recognition test. After completing the course in the simulator, the testers presented the participants with objects that were and were not visible in the simulated environment. The objects were billboards positioned on either side of the road. They compared performance on the incidental recognition task between the single task and mobile phone usage (dual task) condition to assess the impact of phone usage on visual attention. Performance in the dual task condition was significantly lower than in the single task condition. These results suggested that phone usage impaired the visual attention of drivers during the dual task condition.

An alternative explanation was found in the results of Harbluck and Noy (2002) and McCarley et al. (2001). They found that drivers performing an auditory task tended to fixate in the center of their field of vision and reduce the number of fixations in the periphery, which could explain the performance decrement observed in the dual task condition. Strayer, et al. (2003) performed an additional experiment to investigate whether their results were caused by the observed change in drivers' scanning patterns, or if it was the result of attention blindness, looking at but not "seeing", caused by the conversation task.

In order to investigate this issue, the authors repeated the previous experiment and used eye tracking equipment to measure location and duration of fixations in both the single and dual task conditions. First, it was determined that a significant difference in recognition performance existed between the single and dual task condition (better performance in the single task condition). Next, the eye tracking data was evaluated to determine if this effect was a result of a change in the pattern of visual scanning. There was not a significant difference in the number of billboards fixated between the two driving conditions. Additionally, the difference in the length of fixation between the no conversation and the conversation conditions did not vary significantly. As a result of these findings, Strayer, et al. (2003) concluded that a change in visual scanning pattern induced by conversation did not cause the reduction in the recognition task performance. A final analysis considering only those billboards that eye tracking data indicated participants looked at directly revealed a remarkable effect. Participants were only half as likely to recognize a billboard they fixated directly on when using a mobile phone as compared to simply driving.

An additional cause for concern was the potential lack of awareness among certain drivers to the decrease in their driving performance that occurred when they drove and used the phone. While it might have been presumed that drivers compensated for the reduction in their performance when they multi-tasked, it was shown to be otherwise. Lesch and Hancock (2003) studied driving performance with mobile phone use and drivers' perception of their performance. The authors found that female drivers consistently underestimated the impact of phone use on their driving abilities. These participants did not adopt any coping strategies, despite decreased performance, unlike male participants who did change their driving tactics when the performance slipped.

Another phone-induced driving concern was that of situation awareness. Parkes and Hooijemeijer (2000) investigated the impact of concurrent driving and mobile phone use on driver situation awareness. The authors used Endsley's (1988) definition of situation awareness "… perception of the elements of the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p. 97).

The study tested individuals in a static driving simulator with front and rear views. Researchers requested participants to make verbal responses to a variety of questions posed, using a hands free phone set. During the simulation, they instructed the participants to respond as quickly as possible to events that would occur without warning. They assessed situation awareness by asking questions regarding the driving environment at two different times during the test. The results demonstrated a significant decrease in situation awareness among drivers who were also using mobile phones.

The studies of McCarley et al. (2001) and Staryer, et al. (2003) indicate that verbal tasks produced substantial interference with concurrent visual scanning tasks. The implication for mobile phone use and driving was that the critical component of the driving task, visual attention to the driving environment, suffered a decrease in performance. Associated with this decrease was a drop in the individual's knowledge of their environment that limited the likelihood they would respond appropriately, if at all, to critical changes in the driving environment. These effects combined to suggest that mobile phone use while driving was a potentially serious issue.

Application of Multiple Resource Theory

It might be assumed that driving relied primarily on visual perception and that mobile telephony relied on auditory perception. Thus, one would expect little interference as a result of the different perceptual modalities. The two tasks also relied on separate response resources, verbal versus spatial. The aspect of multiple resource theory that was relevant to this dual task situation was that of processing code. While there seemed to be little potential for code conflict at the perceptual and response levels, there could be resource conflicts where central processing was concerned. Driving might be expected to primarily use spatial working memory resources, while holding a conversation on a mobile phone might involve either spatial or verbal working memory resources. The subject of the exchange would determine which resource, spatial or verbal, would be required. For example, if the topic of the conversation required mental imaging, it would demand spatial resources. This posed a potential resource conflict, at the processing code level, that had not yet been examined in the context of the automotive environment.

Wickens and Liu (1988) specifically explored the interaction of processing codes. They designed an experiment with a primary task that required spatial processing code. Then they monitored performance on the primary task, as two different secondary tasks were added to the participant's workload. One secondary task required additional spatial processing while the other demanded verbal processing.

They conducted the study within the context of the military aviation environment. The primary task was a manual tracking task performed with a joystick; this task was spatial in nature. Participants then performed a secondary task of varying difficulty. They either made a spatial decision task (a prediction of future location for an enemy aircraft) classified as easy or hard or a verbal decision task (simple arithmetic and a choice) which was also easy or hard. The final variable in the experiment was the response modality for the secondary task, that was either spatial (a button press) or verbal (an oral response). They evaluated the impact of the secondary tasks by processing code, difficulty, and response mode in terms of performance decrements for the tracking task, response time, and decision accuracy.

The results indicated a greater drop in performance of the tracking task when performing the spatial decision task as opposed to the verbal decision task. Response time decrement decreased for the difficult verbal condition compared to the easy verbal task, which was unexpected. However, the performance decrement for response time was not significantly different for the two levels of difficulty of the spatial coded secondary task. The final dual task performance measure, decision accuracy, revealed one significant performance decrement. The performance of a difficult spatial task was statistically worse than the performance of a difficult verbal task.

These results were, for the most part, consistent with the structure of multiple resource theory. That is, multiple resource theory predicted that two tasks demanding the same resource for central processing would produce greater interference than two tasks that used separate resources. This rule accounted for the decreases in performance on the primary task when the secondary task required additional spatial processing. The reduced performance decrement associated with the increase in difficulty of the verbal secondary task on the response time measure was both unexpected and unexplained by Wickens and Liu (1988). However, the impact of the various secondary tasks did demonstrate the overall negative effect of dual tasks that required the same processing code. This effect was of primary relevance to the current study.

The research reviewed thus far has supported the hypothesis that mobile phone use induces a significant decrement in driving performance when the two tasks were performed concurrently. However, very little is known about the source of interference of mobile phone use with the driving task. The difficulty could have been a central bottle neck, meaning that the central processor of Baddeley's working memory model could not perform the necessary processing to simultaneously support both tasks. Alternatively, the conflict could have been the result of a specific, visuo-spatial or articulatory, resource limitation.

Reconsidering the Strayer and Johnston (2001) paper with multiple resource theory as a guide raised an important question. What were the processing codes required by the two secondary tasks, listening and conversing. The authors did not relate the content of the conversations or of the radio broadcasts. The processing codes required by each might have offered an explanation as to why the levels of interference varied between the two conditions.

Recarte and Nunes (2000) reported results that demonstrated the predictions of multiple resource theory. Using two tasks, one articulatory and one visuo-spatial in nature, that were equivalent in difficulty, they observed the level of interference with the primary visuo-spatial driving task. The impact of the visuo-spatial secondary task was significantly greater than the articulatory task. These results matched with multiple resource theory and further supported its relevance to the driving/multi-task environment.

The Wickens and Liu (1988) study shared a similar structure with the current experiment. The primary driving task had significant tracking requirements, and conversations that were spatial in nature produced a similar resource demand like the spatial decision task that required the maintenance and manipulation of a mental model. These similarities suggested that the results would be of interest for either their support or their conflict with these earlier findings in the aviation context.

THE PRESENT STUDY

The current study evaluated the effect of processing codes on interference levels observed in automobile operation with concurrent mobile phone use. This investigation explored aspects of multiple resource theory complementary to those addressed by Recarte and Nunes (2000). Specifically, the experiment was structured to examine the relative effects of spatial and verbal processing codes of conversation on simulated driving behavior and performance. This experiment was unique in two significant aspects. First, the participants were engaged in more naturalistic conversations as opposed to "laboratory" tasks. This was a decision influenced by Strayer and Johnston's (2001) finding that a shadowing task did not produce interference, whereas a more generative verbal task did produce interference. The second difference was that this study sought to measure driving performance directly while Recarte and Nunes only measured variations in ocular behavior in order to extrapolate the potential impact on driving performance.

This study also re-evaluated two variables identified as significant in previous research. McCarley et al. (2001) and Alm and Nilsson (1995) found the effect of age to be significant in their studies. Because young drivers performed significantly worse in the past, this study evaluated driving experience for significance. The impact of phone use by inexperienced drivers was of particular interest in light of recent legislative proposals. California State Senator Debra Bowen recently sponsored a bill that proposed a ban on mobile phone use for drivers under the age of 18 (Rau, 2004). Another potentially important variable was gender, because it reached statistical significance in the work of Lesch and Hancock (2003).

Hypotheses

Two specific hypotheses were tested during the experiment. The first hypothesis is that driving performance in the dual task condition, driving and conversing, will be degraded in comparison to driving performance in the single task driving condition. This hypothesis is based on the working memory model (Baddeley, 1999) and multiple resource theory (Wickens, 1991). The working memory model suggests that an overload of the central executive would create a limitation on performance. If adding the conversation degrades driving performance than the central executive may be overloaded by the combination. Multiple resource theory states that two tasks that require processing at the same stages (perception, working memory or responding) are more likely to interfere with one another. Driving and conversation both require processing at these all three stages so multiple resource theory would predict some performance degradation in one of the two tasks. Therefore a significant decrease in driving performance between the single task and dual task conditions will support both models of cognition. This change in performance will be evaluated across nine different measures of driving performance. A significant decrease in driving performance during the dual task condition for the majority of the nine objective driving measures will indicate support for the hypothesis.

The second hypothesis is that the visuo-spatial conversation will cause a significant degradation in driving performance compared to that caused by the articulatory conversation. This hypothesis is based on multiple resource theory (Wickens, 1991) which asserts that two tasks that require the same processing code resources are more likely to conflict than tasks which utilize different processing codes. The driving task requires visuo-spatial resources as does a conversation designed to require visualization, or mental imagining, while an articulatory conversation would use different processing codes than the driving task. Therefore, multiple resource theory will be supported in its application at the conversation content level for conversing while driving if the visuo-spatial condition produces worse driving performance than the articulatory condition across the majority of the nine objective driving measures.

METHODS

Design

This study employed a mixed design with three factors. The first factor was the conversation processing code that had two levels: articulatory and visuo-spatial coding. The study compared this within participants and against a baseline condition of driving without conversation. The second "between-participants" factor was experience, that included two levels: novice (≤ 3 years driving experience) versus experienced (10 or more years driving experience). The third factor between participants was gender that had two levels: male versus female.

The experiment measured the performance of participants during three scenarios: driving with no secondary task, driving while participating in a conversation requiring articulatory processing codes, and driving while participating in a conversation requiring visuo-spatial processing codes. The study divided participants into four groups as a function of the experience and gender factors, as shown in Table 1.

Table 1. Experimental Design

<table>
<tr><th rowspan="2"></th><th rowspan="2"></th><th rowspan="2">Single task</th><th colspan="2">Dual task</th></tr>
<tr><th>Articulatory coding</th><th>Visuo-spatial coding</th></tr>
<tr><td rowspan="2">Novice drivers (≤ 3 years of experience)</td><td>Female n = 8</td><td>Driving</td><td>Driving + articulatory conversation</td><td>Driving + visuo-spatial conversation</td></tr>
<tr><td>Male n = 8</td><td>Driving</td><td>Driving + articulatory conversation</td><td>Driving + visuo-spatial conversation</td></tr>
<tr><td rowspan="2">Experienced drivers (10≥ years of experience)</td><td>Female n = 8</td><td>Driving</td><td>Driving + articulatory conversation</td><td>Driving + visuo-spatial conversation</td></tr>
<tr><td>Male n = 8</td><td>Driving</td><td>Driving + articulatory conversation</td><td>Driving + visuo-spatial conversation</td></tr>
</table>

The first condition, driving with no secondary task, established a baseline for participant performance. Participant performance, in the two conditions with secondary tasks, was then analyzed to determine the impact of processing code on interference.

Participants

Thirty-two drivers were recruited to participate in the study. Each participant had normal or corrected vision and hearing and held a valid driver's license. In addition, each participant owned and, at least occasionally, used their mobile phone while driving.

The attached screener document was used to qualify the participants (see Appendix A).

Apparatus

The experiment was performed using driving simulation software, Midtown Madness by Microsoft, running on a personal computer. The computer was a Dell desktop with a Pentium 4 processor, 512 MB of RAM and a 128 MB video card. The program was configured to operate in the "cruise" mode, in which drivers could freely navigate the simulation of downtown Chicago. The driving conditions were set as follows: a traffic density of 3 out of 20, a pedestrian density of 5 out of 20, and a police density of 0 out of 20. Participants interacted with the simulator using a Saitek R440 force feedback wheel with foot pedals. (see Figure 3). The following configuration of the driving controls was used: the steering sensitivity at the lowest possible level, controller dead zone at 6 out of 20, the force-feedback scale at 14 out of 20, and road force at 16 out of 20. The display stimulus was a 21" Viewsonic LCD monitor. A hands free intercom system provided the means for holding conversations between the driver and the experimenter. This was done to simulate the use of a hands free phone set. The experiment uses a hands free approach to eliminate the peripheral physical demands of phone use as a potential cause for any differences in driving performance that were observed.

Figure 3. Driving simulator.

Procedure

After signing the consent form, the participants listened to a brief set of instructions, which provided the context for the experimental session (see Appendix B). Participants entered the lab and were seated at the driving simulator and were read another set of instructions specific to the operation of the simulator (see Appendix C). They spent at least 5 minutes familiarizing themselves with the equipment and software, driving around a simulated town at their leisure, while adhering to all "rules of the road", speed limits, etc.

Participants then performed the simulated driving task under each of the following conditions: single task, dual task with visuo-spatial processing code, and dual task with articulatory processing code. Under the single task condition, the participant had no secondary task to perform. During the dual task with visuo-spatial processing code, subjects participated in conversations requiring visual processing codes (for example discussing directions to a particular location in the simulated city, see Appendix G). The test moderator communicated tasks devised to require visual code processing via the hands free intercom system. While performing the dual task with articulatory processing code, participants took part in conversations devised to require articulatory processing codes (for example discussing an abstract concept, see Appendix H), again using the intercom to simulate a hands free phone set. Both secondary task conditions were constructed in an effort to maintain a naturalistic atmosphere. Discussions did not involve "artificial" verbal tasks, but rather replicated normal conversation as much as possible.

The order of task conditions presented to participants were arranged in a Latin square such that each condition would be presented first, second, and third an equal number of times. The secondary tasks were not administered in a block format, with all of one type of conversation then the other; but rather were presented in alternating blocks. The two types were presented, one than the other, with single task conditions between until an equal amount of time had been spent engaged in each type of conversation. A participant activity outline (see Appendix E) and sample conversations by coding (Appendixes G and H) are included.

Data was collected using scan converter recordings of the software and video recordings of the driver. The recordings of each session were evaluated for specific performance criteria under each of the three conditions (single task driving condition, driving with visuo-spatial processing code conversation responses and driving with articulatory processing code conversation responses). Activity Catalog Tool (ACT) software was used to record the relevant performance variables. ACT runs on the Macintosh platform and is a tool for recording and encoding observations. ACT allows users to associate events with up to nine keys. These keys can then be depressed during a review session and ACT will provide the frequency and duration for each event associated with the keys. This enabled all of the dependent measures to be coded during one review of each session. ACT also enabled the identification of the experimental condition at each point during the session and the association of the driving measure performance with that condition. As a result one viewing of a session with ACT could produce the total time in each experimental condition and the frequency and duration of each driving performance measure. The data from all of the sessions were then transcribed into a spreadsheet and statistical analyses were conducted using SPSS statistical software.

After completing the simulated driving portion of the study, each participant was asked to complete a questionnaire (see Appendix F) regarding their experience and performance during the session.

Dependent Measures:

The recording permitted analysis of the following dependent measures:

- Frequency of lane deviations (the vehicle was not completely within one lane)
- Duration of lane deviations
- Frequency of collisions (striking other vehicles, objects or leaving the road)
- Failure to obey signal (failing to stop at a signal or failing to respond to a changed signal e.g., when a traffic light turns green)
- Frequency of braking control errors (stopping short, late or failing to stop)
- Frequency of driving more than 5 mph above the speed limit (driving more than 5 mph faster than the appropriate speed limit, determined by monitoring the speedometer)
- Duration of driving more than 5 mph above the speed limit (driving more than 5 mph faster than the appropriate speed limit)
- Frequency of driving more than 5 mph below the speed limit (driving more than 5 mph slower than the appropriate speed limit, determined by monitoring the speedometer)
- Duration of driving more than 5 mph below the speed limit (driving more than 5 mph slower than the appropriate speed limit)

Each instance of the above events was recorded through review of the video data. Performance was evaluated for the period after the question was asked until 10 seconds after the completion of the participant's response or until the beginning of the experimenter began to ask the next question (see Figure 4). This 10 second period is to accommodate the possibility that a failure in perception during the response might result in a measurable driving error after the participant had completed their response. This concept is supported in the results of Abdel-Aty (2003).

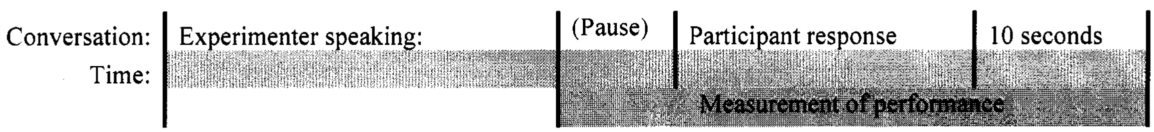

Figure 4. Timeline for performance measurement.

An overall session timeline can be found in Appendix E.

Analysis

The first phase of data analysis involved a 3 X 2 X 2 mixed ANOVA for each driving performance measure. A comparison of driver performance was made between the baseline condition (no secondary task) and the two secondary task conditions (driving while conversing for each processing code). This analysis was conducted for the entire participant pool as well as for the subgroups of experience, gender, and experience by gender.

If there was a significant difference between the conversation and no conversation conditions, the analysis proceeded into the second phase. During the second phase of analysis, post hoc comparisons were evaluated to investigate any differences that existed between the different types of coded conversation (articulatory and visuo-spatial), experience and gender.

This study will support the applicability of multiple resource theory to this dual task condition if the results show a significant decrement in driving performance across the various measures for the visuo-spatial conversation condition. If there is no performance decrement for the visuo-spatial conversation condition or if performance for this condition is not significantly worse than performance under the articulatory conversation condition, then the study will not demonstrate the relevance of multiple resource theory for these conditions.

RESULTS

Analysis of Objective Data

The first step of the statistical analysis process was to evaluate whether or not each participant spent an equal amount of time in each experimental condition; single task driving, driving with visuo-spatial response, and driving with articulatory response. The conversations were structured to be naturalistic and as a result there was some variance in overall length. Additionally, the length of the response would affect the amount of time the experimenter spoke and thus the measurable driving performance time for a participant (see Figure 4).

The comparison of time spent in each condition by participant was made by performing a within subjects ANOVA. The variance in condition time was found to be significant $F(2, 29) = 6.684$ $p < .05$. Since the participants spent different amounts of time in the three conditions the dependent measures were normalized. The descriptive statistics for the time spent in each experimental condition are contained in the table below.

Table 2. Descriptive Statistics for Time Spent in Each Experimental Condition Measured in Seconds

Experimental condition	Mean (sec.)	Std. deviation	N
Single task driving	1244.1	25	32
Driving + visuo-spatial response	1231.0	32.9	32
Driving + articulatory response	1216.5	37.6	32

The dependent measures based on frequency were normalized by converting all time measures to minutes then dividing each participant's performance measures by the amount of time spent in the associated condition. For example the number of lane deviations that occurred during the single task driving condition was divided by the total amount of time (in minutes) a participant spent in the single task driving condition. The measures based on duration were simply converted to minutes and divided by the normalized frequency of the associated event to determine the normalized average duration in minutes. The following is a list of the resulting measures:

- Normalized frequency of lane deviations
- Normalized mean duration of lane deviations by condition
- Normalized frequency of collisions by condition
- Normalized frequency of failure to obey signal by condition
- Normalized frequency of braking control errors by condition
- Normalized frequency of driving more than 5 mph above the speed limit by condition
- Normalized mean duration of driving more than 5 mph above the speed limit by condition
- Normalized frequency of driving more than 5 mph below the speed limit by condition
- Normalized mean duration of driving more than 5 mph below the speed limit by condition

Analyses were then conducted for each dependent measure. A significance level of $p < .05$ was used in all cases. Mauchly's test of sphericity was conducted for each measure. Where Mauchly's W value was found to be significant sphericity was assumed in the determination of F values. When sphericity was not significant Greenhouse-Geisser was used to determine F values.

Normalized Frequency of Lane Deviations

There was no main effect for normalized frequency of lane deviations by experimental condition [$F(2,28) = .461$, $p = >.05$, not significant, sphericity assumed]. There was a main effect for gender [$F(1,28) = 13.835$, $p = <.05$]. Male participants had fewer lane deviations (mean = 1.26) than female participants (mean = 2.29). This effect is displayed in Table 3 and Figure 5.

Table 3. Descriptive Statistics for Mean Normalized Frequency of Lane Deviation by Gender

Gender	Mean	Std. deviation	N
Male	1.26	.195	16
Female	2.29	.195	16

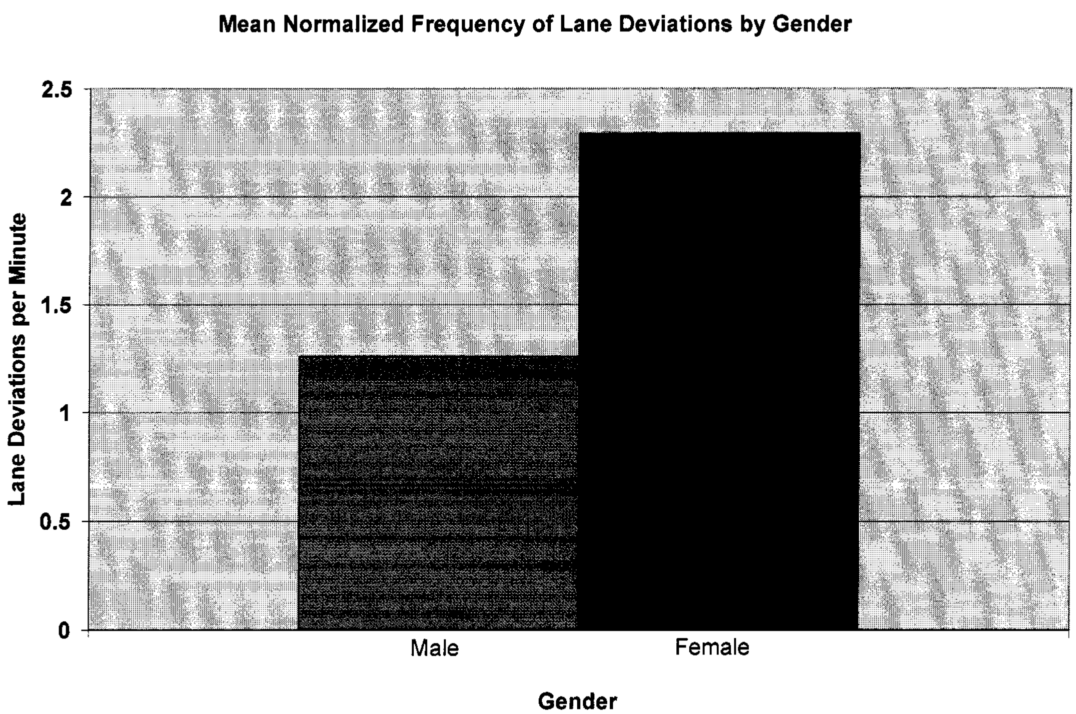

Figure 5. Mean normalized frequency of lane deviations by gender.

There were no other significant effects or interactions.

Normalized Duration of Lane Deviations

There was no main effect for normalized duration of lane deviations by experimental condition [$F(2,28) = .690$, $p = > .05$, not significant]. A main effect was observed for experience [$F(1,28) = 4.469$, $p = < .05$]. Post-hoc comparisons revealed that novice participants lane deviations were not as long (mean = .026 minutes) as were experienced participants (mean = .034 minutes). This effect is depicted in Table 4 and. Figure 6.

Table 4. Descriptive Statistics for Mean Normalized Duration of Lane Deviation by Experience

Experience Group	Mean (minutes)	Std. deviation	N
Novice	.026	.003	16
Experienced	.034	.003	16

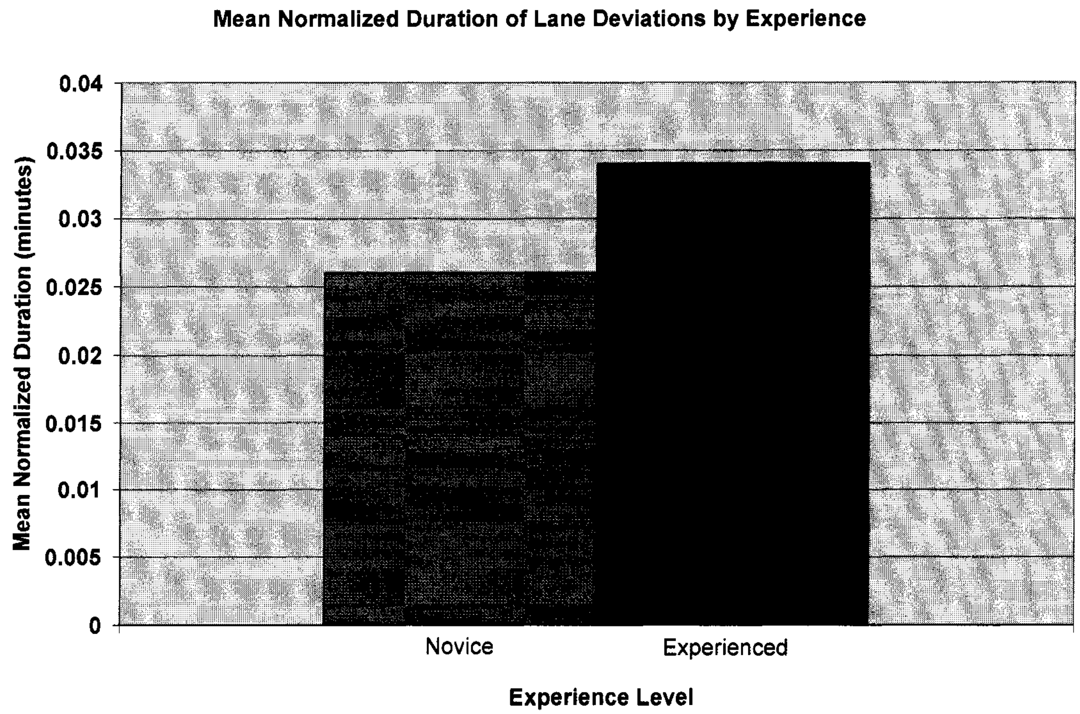

Figure 6. Mean normalized duration of lane deviations by experience.

A significant interaction was observed between processing codes and experience for the normalized duration of lane deviations [$F(2,28) = 5.33$, $p = .009$]. While both groups had similar means in the single task condition [novice (mean = .0291) and experienced (mean = .0323)] novice participants improved under both dual task conditions while experienced drivers performed more poorly in the visuo-spatial processing code condition. Table 5 and Figure 7 show this interaction.

Table 5. Mean Normalized Duration of Lane Deviations by Experience and Experimental Condition

Experimental condition	Experience	Mean (min.)	Std. deviation	N
Single task driving	Novice	.0291	.00974	16
	Experienced	.0323	.01287	16
Driving + visuo-spatial response	Novice	.0230	.01010	16
	Experienced	.0375	.01290	16
Driving + articulatory response	Novice	.0260	.01212	16
	Experienced	.0313	.01344	16

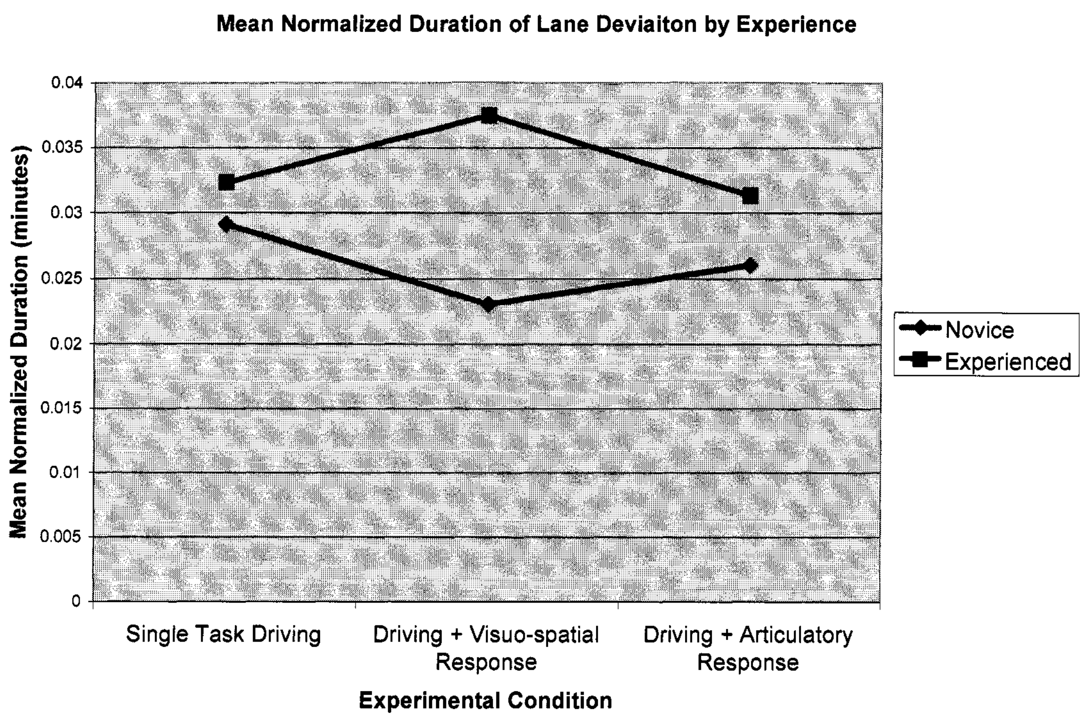

Figure 7. Mean normalized duration of lane deviations by experience and experimental condition.

There were no other significant effects or interactions.

Normalized Frequency of Collisions

There was no main effect for normalized frequency of collisions per minute by experimental condition [F(2,28) = .255, p = > .05]. A main effect was observed for gender [F(1,28) = 8.59, p = <.05]. Male participant had a lower mean number of collision per minute (mean = .001) than did female participants (mean = .010). This effect is depicted in Table 6 and Figure 8.

Table 6. Descriptive Statistics for Mean Normalized Frequency of Collisions by Gender

Experience group	Mean	Std. deviation	N
Male	.001	.002	16
Female	.010	.002	16

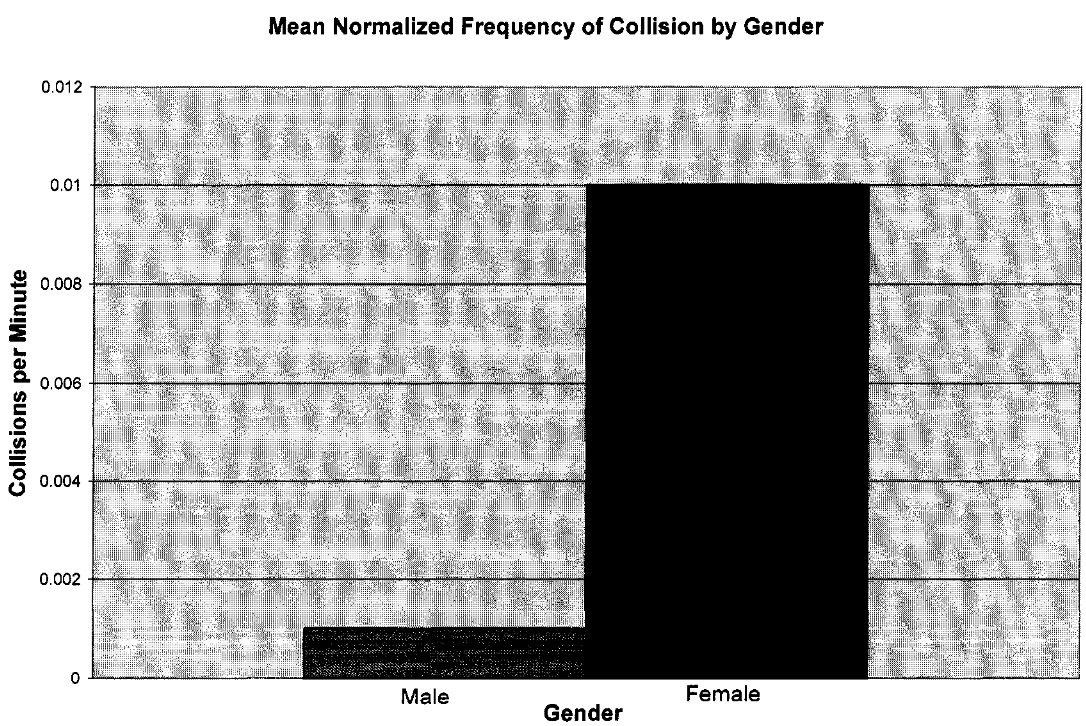

Figure 8. Mean normalized frequency of collisions by gender.

There were no other significant effects or interactions.

Normalized Frequency of Failure to Obey Signal

There was no main effect for normalized frequency of failure to obey signal [F (2, 28) = 2.365, p = >.05 not significant, sphericity assumed]. There were no other significant effects or interactions.

Normalized Frequency of Braking Control Errors

There was a main effect for normalized frequency of braking control errors by experimental condition [F (2, 28) = 8.107, p = < .05]. Participants had the lowest number of braking control errors in the single task condition (mean = .0452). Both the articulatory response condition (mean = .0688, p = < .05) and the visuo-spatial response condition (mean = .1000, p = < .05) were significantly worse. The visuo-spatial condition was also significantly worse than the articulatory response condition (p = < .05). The results indicate that participants were significantly impaired in their braking rate performance in the two speaking conditions and that they were most impacted by the visuo-spatial response condition. This effect can be seen in Table 7 and Figure 9.

Table 7. Mean Normalized Frequency of Braking Control Errors by Experimental Condition

Experimental condition	Mean	Std. deviation	N
Single task driving	.0452	.05460	32
Driving + visuo-spatial response	.1000	.07487	32
Driving + articulatory response	.0688	.06080	32

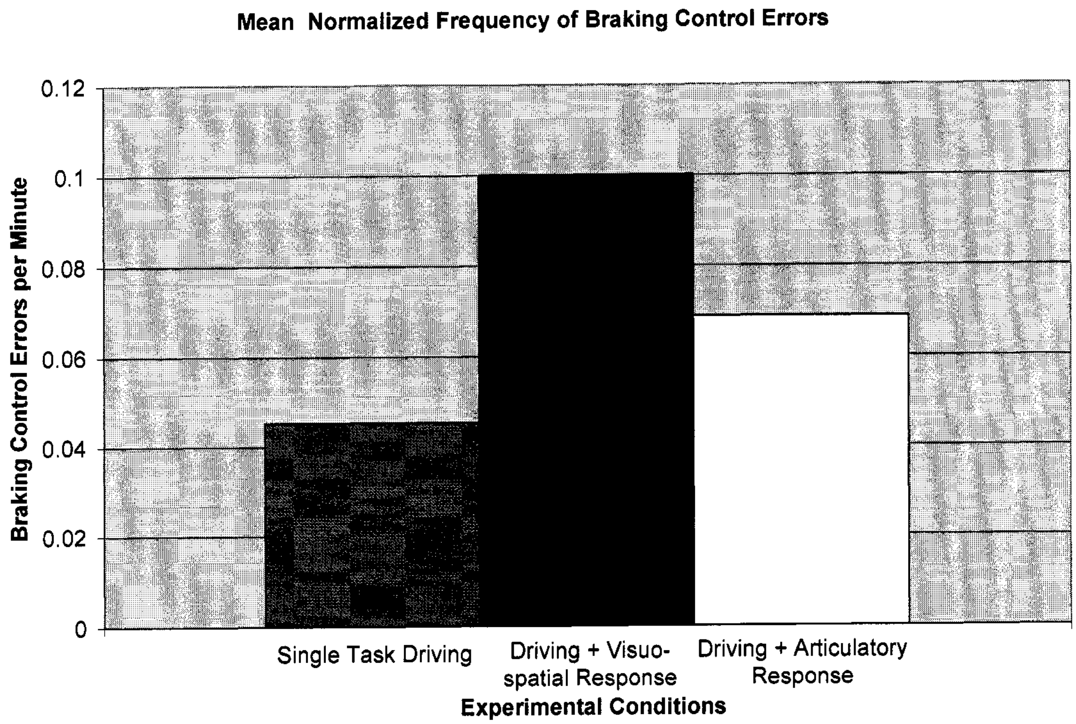

Figure 9. Mean normalized frequency of braking control errors by experimental condition.

There were no other significant effects or interactions.

Normalized Frequency of Driving More Than 5 mph Above the Speed Limit

There was a main effect for normalized frequency of driving more than 5 mph above the speed limit by experimental condition [$F(2, 28) = 26.26$, $p = < .05$]. Participants had the fewest instances of exceeding the speed limit in the single task condition (mean = .427). Both the articulatory response condition (mean = .843, $p = < .05$) and the visuo-spatial response condition (mean = .853, $p = < .05$) were significantly worse. Participants were more likely to exceed the speed limit in the two talking conditions. This effect can be seen in Table 8 and Figure 10 below.

Table 8. Mean Normalized Frequency of Driving More Than 5 mph Above the Speed Limit by Experimental Condition

Experimental condition	Mean	Std. deviation	N
Single task driving	.4269	.26898	32
Driving + visuo-spatial response	.8530	.48083	32
Driving + articulatory response	.8427	.47540	32

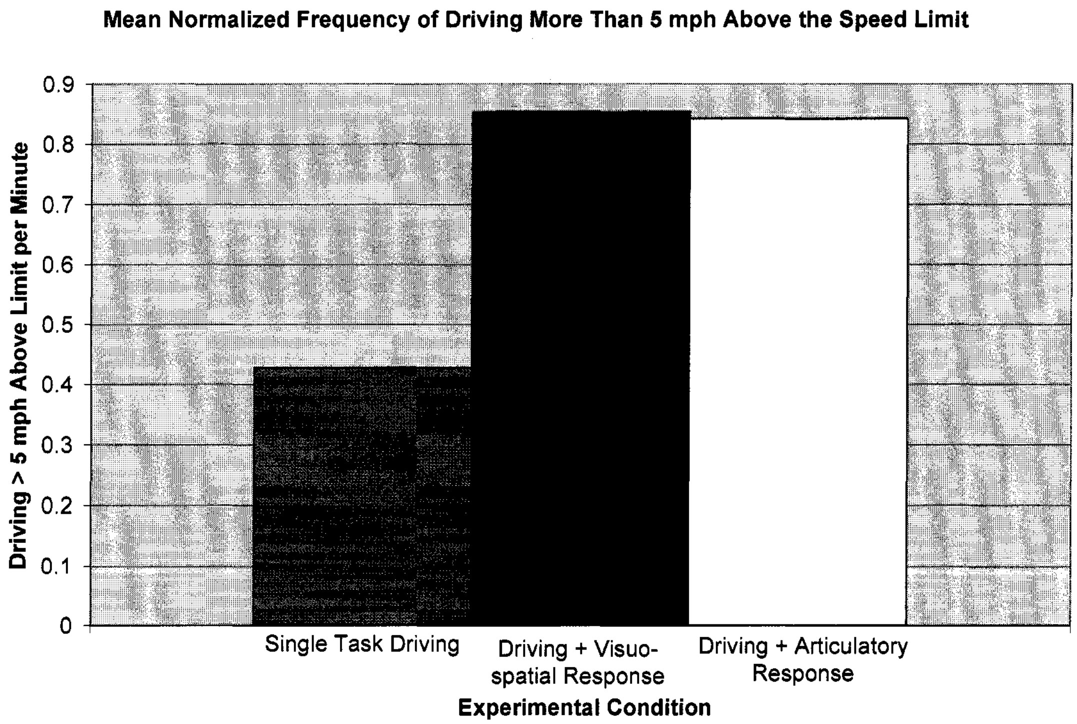

Figure 10. Mean normalized frequency of driving more than 5 mph above the speed limit by experimental condition.

There were no other significant effects or interactions.

Normalized Duration of Driving More Than 5 mph Above the Speed Limit

There was a main effect for normalized duration of driving more than 5 mph above the speed limit by experimental condition [F (2, 28) = 11.584, p = < .05]. Participants had the shortest average duration of exceeding the speed limit in the single task condition (mean = .054 minutes). Both the articulatory response condition (mean = .086, p = < .05) and the visuo-spatial response condition (mean = .082, p = < .05) were significantly worse. Participants spent more time exceeding the speed limit in the two talking conditions. This effect can be seen in Table 9 and Figure 11.

Table 9. Mean Normalized Duration of Driving More Than 5 mph Above the Speed Limit by Experimental Condition

Experimental condition	Mean (min.)	Std. deviation	N
Single task driving	.054	.005	32
Driving + visuo-spatial response	.082	.006	32
Driving + articulatory response	.086	.007	32

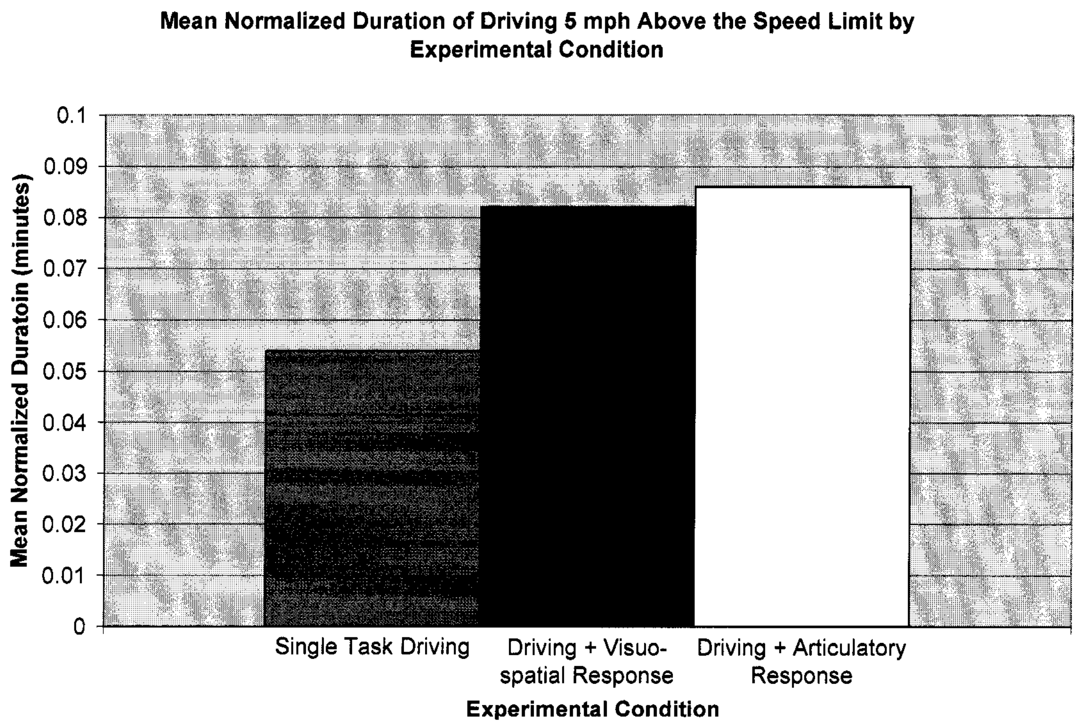

Figure 11. Mean normalized duration of driving more than 5 mph above the speed limit by experimental condition.

There were no other significant effects or interactions.

Normalized Frequency of Driving More Than 5 mph Below the Speed Limit

There was a main effect for normalized frequency of driving more than 5 mph below the speed limit by experimental condition [$F(2, 28) = 53.444$, $p = < .05$]. Participants had the fewest instances of slowing below the speed limit in the single task condition (mean = .4231). Both the articulatory response condition (mean = .7230, $p = < .05$) and the visuo-spatial response condition (mean = .8871, $p = < .05$) were significantly worse than the single task condition. The visuo-spatial condition was also significantly worse than the articulatory response condition ($p = < .05$). The results suggest that during both speaking conditions participants found it more difficult to maintain the proper speed with the visuo-spatial condition being the most difficult. This effect can be seen in Table 10 and Figure 12.

Table 10. Mean Normalized Frequency of Driving More Than 5 mph Below the Speed Limit by Experimental Condition

Experimental condition	Mean	Std. deviation	N
Single task driving	.4231	.36059	32
Driving + visuo-spatial response	.8871	.41852	32
Driving + articulatory response	.7230	.46644	32

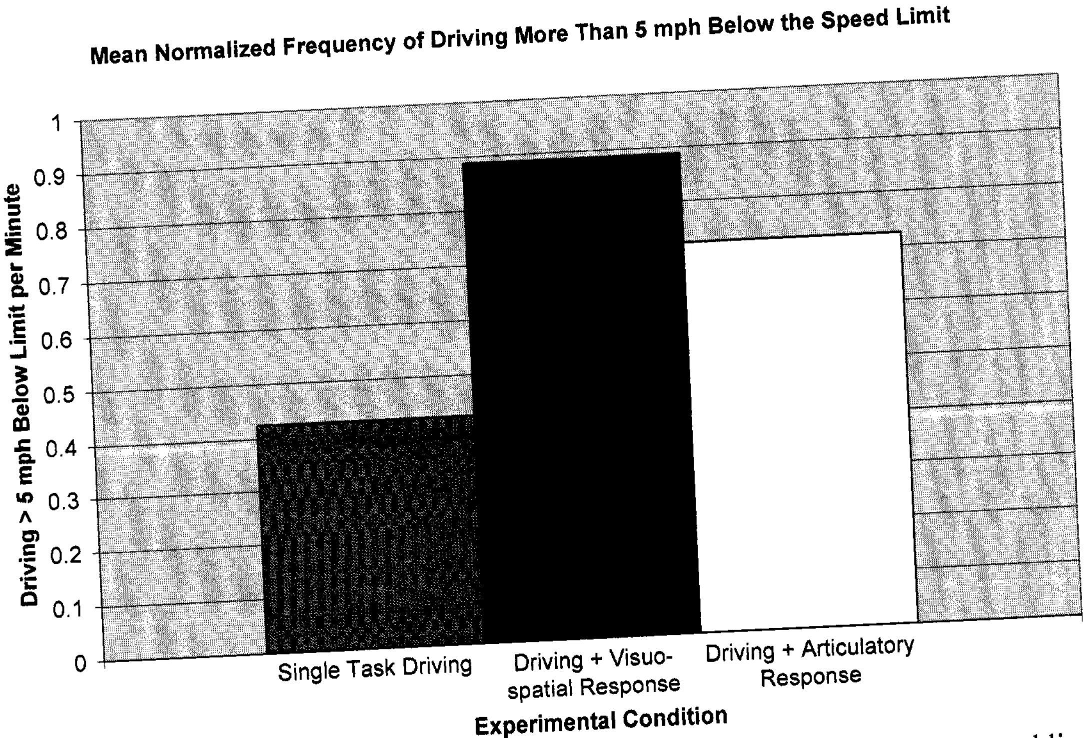

Figure 12. Mean normalized frequency of driving more than 5 mph below the speed limit by experimental condition.

There was also a significant interaction of experience with processing codes [$F(2,28) = 3.91$, $p = < .05$]. While both groups had similar means in the single task condition [novice (mean = .4123) and experienced (mean = .423)] experienced drivers demonstrated a larger decrement in performance in the visuo-spatial and articulatory response conditions. Both novice and experienced drivers had difficulty maintaining their speed in the dual task conditions, however, the experienced drivers showed a greater drop in performance. This interaction can be seen in Table 11 and Figure 13.

Table 11. Mean Normalized Frequency of Driving More Than 5 mph Below the Speed Limit by Experience and Experimental Condition

Experimental condition	Experience	Mean	Std. deviation	N
Single task driving	Novice	.4123	.43448	16
	Experienced	.4339	.28231	16
Driving + visuo-spatial response	Novice	.7561	.36306	16
	Experienced	1.018	.43996	16
Driving + articulatory response	Novice	.6156	.46289	16
	Experienced	.8303	.45912	16

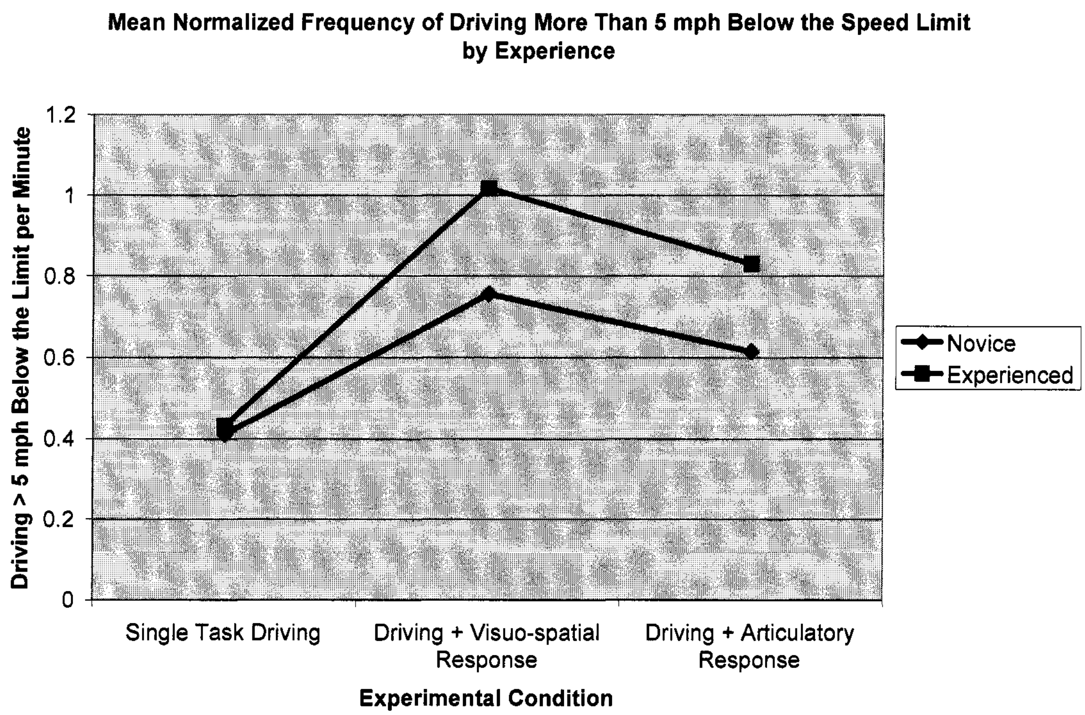

Figure 13. Mean normalized frequency of driving more than 5 mph below the speed limit by experience and experimental condition.

There were no other significant effects or interactions.

Normalized Duration of Driving More Than 5 mph Below the Speed Limit

There was a main effect for normalized duration of driving more than 5 mph below the speed limit by experimental condition [F (2, 28) = 9.448, p = < .05, sphericity assumed]. Participants had the shortest average "driving slowly" event time in the single task condition (mean = .069 minutes). Both the articulatory response condition (mean = .1084 minutes, p = < .05) and the visuo-spatial response condition (mean = .1082 minutes, p = < .05) were significantly worse. Participants spent more time driving more than 5 mph below the speed limit in the two talking conditions. This effect can be seen in Table12 and Figure 14.

Table 12. Mean Normalized Duration of Driving More Than 5 mph Below the Speed Limit by Experimental Condition

Experimental condition	Mean (min.)	Std. deviation	N
Single task driving	.0690	.04307	32
Driving + visuo-spatial response	.1082	.05583	32
Driving + articulatory response	.1084	.07049	32

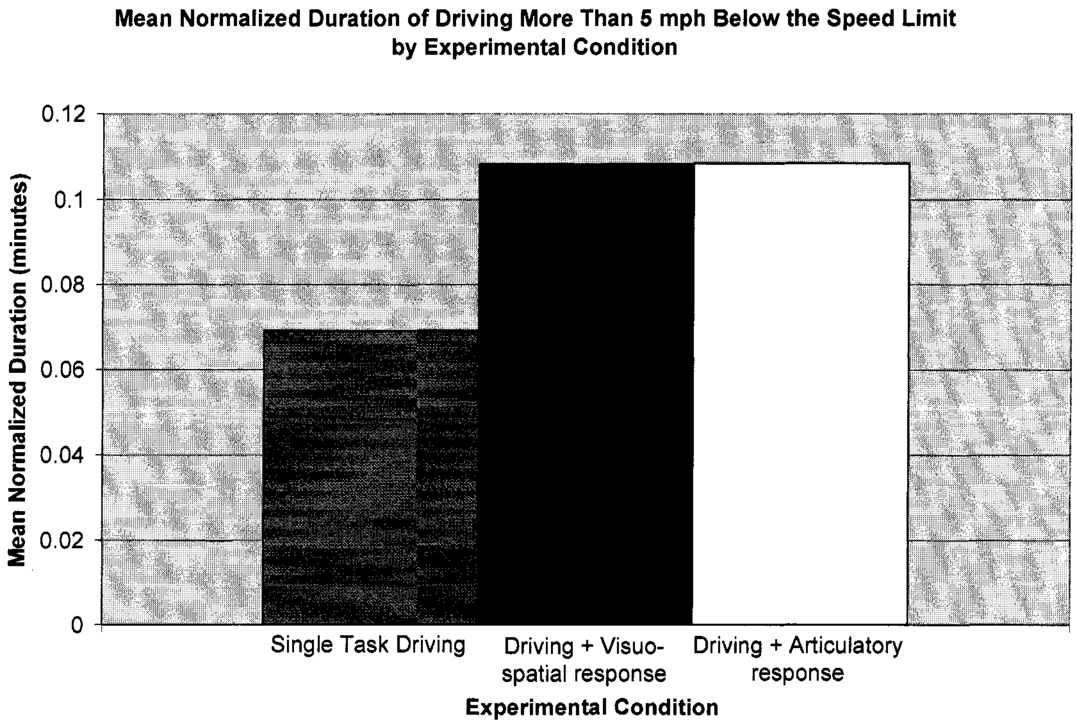

Figure 14. Mean normalized duration of driving more than 5 mph below the speed limit by experimental condition.

There were no other significant effects or interactions.

Summary of Objective Results

Five of the nine measures had significant main effects by processing code. A summary of the statistical analysis of the objective measures for processing code is depicted in Table 13.

Table 13. Summary of Statistical Analysis and Mean Values of Objective Measures for Processing Code

Driving performance measure		Experimental condition: Single task	Driving + visuo-spatial conversation	Driving + articulatory conversation
		Mean values		
Normalized frequency of lane deviations		1.7450	1.8250	1.7530
Normalized duration of lane deviations (min)		0.0307	0.0303	0.0286
Normalized frequency of collisions		0.0046	0.0150	0.0460
Normalized frequency of failure to obey signal		0.0090	0.0198	0.0061
Normalized frequency of braking control errors	✔	0.0452	0.1000	0.0688
Normalized frequency of driving > 5 mph above speed limit	✔	0.4269	0.8530	0.8427
Normalized duration of driving > 5 mph above speed limit (min)	✔	0.0540	0.0819	0.0864
Normalized frequency of driving > 5 mph below speed limit	✔	0.4231	1.0181	0.8303
Normalized duration of driving > 5 mph below speed limit (min)	✔	0.0690	0.1082	0.1084

Indicates best performance for a given criteria

✔ Indicates statistically significant superior performance to other conditions

Analysis of Subjective Data

Each participant completed a subjective post participation questionnaire upon completion of their session. The data from these questionnaires is summarized in this section.

Question 1.

1. Please rate how accurately the driving simulator modeled actual driving:
(1, very poorly - 10, very well)

______

The average score from participants was 6 with a range from 4 to 8. On the whole participants found the simulator of slightly better than neutral in its ability to model actual driving.

Question 2.

2. Please rank your driving performance during the following conditions:
(1, best ; 2, middle; 3, worst)

______Driving with no other activities

______Driving and listening

______Driving and speaking

The average score for the single task driving condition was 1.125 making it the condition when participants expected the driving to be best. Participants scored driving and listening with a value of 2.094. Driving and talking received the worst rating with a mean of 2.78. Participants' comparisons of these conditions are depicted in the Figure 15.

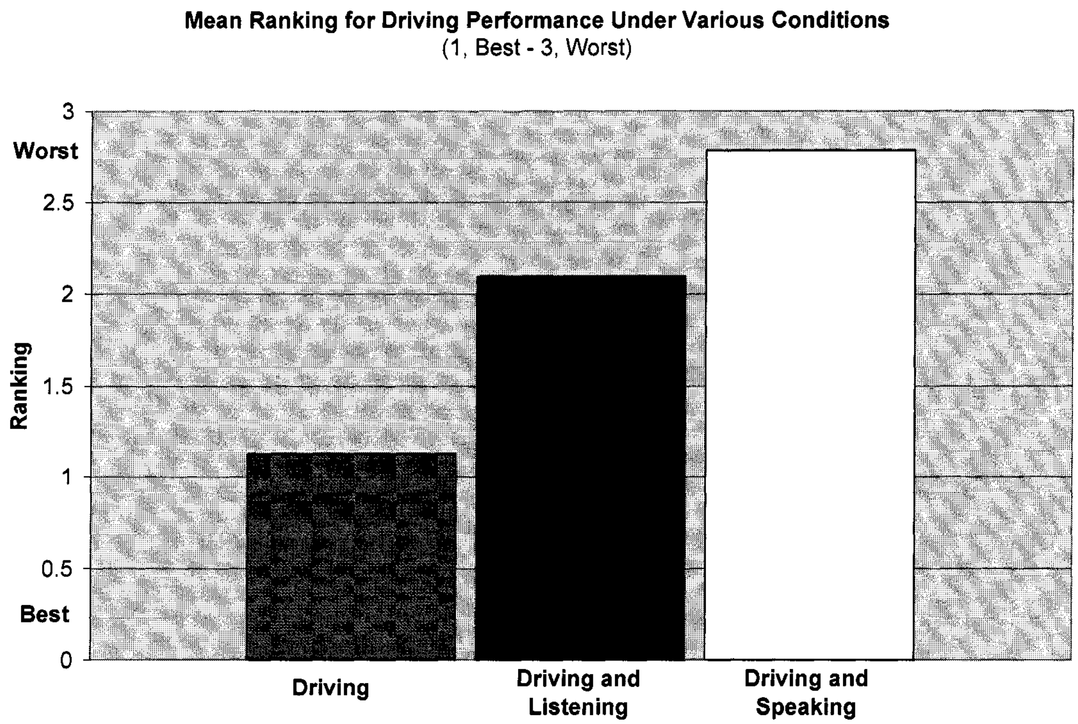

Figure 15. Mean ranking for driving performance under various conditions.

Question 3.

3. Please rank your driving performance during the following conditions:
(1, best - 3, worst)

______Driving with no other activities

______Driving and discussing concepts (government--social services, election issues, pollution-- world issues –the environment, poverty, nuclear proliferation, etc.— and energy – alternative fuel vehicles, nuclear and solar power)

______Driving and discussing things and places (describing the home you grew up in, museums, concerts, stores, and driving directions.)

The average score for Driving with no other activities was 1.093 indicating that nearly all participants found the single task easier than the two response conditions. The average score for driving and discussing things and places, which is the visuo-spatial response condition, was 2.12. The average score for the driving and discussing concepts, which equates to the articulatory response condition, was 2.78. This indicates that the majority of participants believed this condition was the one in which their driving performance would be its lowest. This comparison is shown in Figure 16.

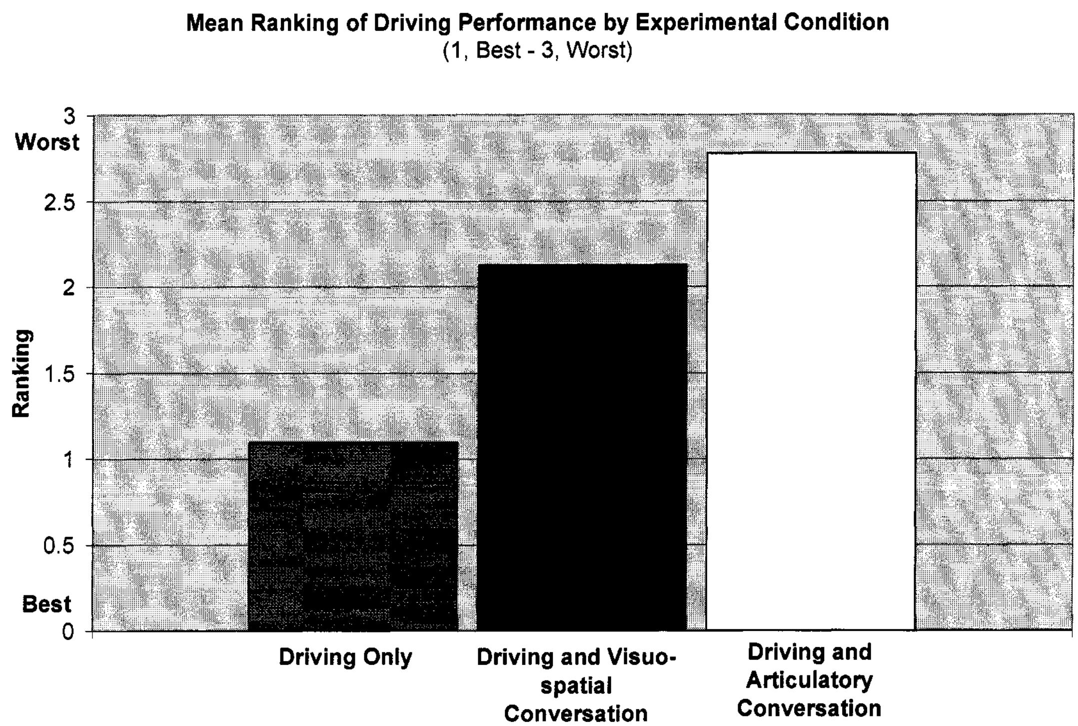

Figure 16. Mean ranking of driving performance by experimental condition.

Question 4.

4.Please rank the following conditions as they relate to the amount of workload you experienced during today's simulation:
(1 highest workload – 4 lowest workload)

_____Driving with no other activities

_____Driving and listening

_____Driving and speaking about concepts (government--social services, election issues, pollution-- world issues –the environment, poverty, nuclear proliferation, etc.— and energy – alternative fuel vehicles, nuclear and solar power)

_____Driving and speaking about places or things (describing the home you grew up in, museums, concerts, stores, and driving directions.)

Driving with no other activates had an average score of 3.8 indicating that most participants considered it to be the least demanding condition. Driving and listening was ranked at 2.62. Driving and speaking about concepts (articulatory) had an average score of 1.44, which would be the most demanding condition. Driving and speaking about places and things (visuo-spatial) had an average score of 2.06. Thus the participants believed the visuo-spatial condition produced less workload than the articulatory condition. This is depicted in Figure 17.

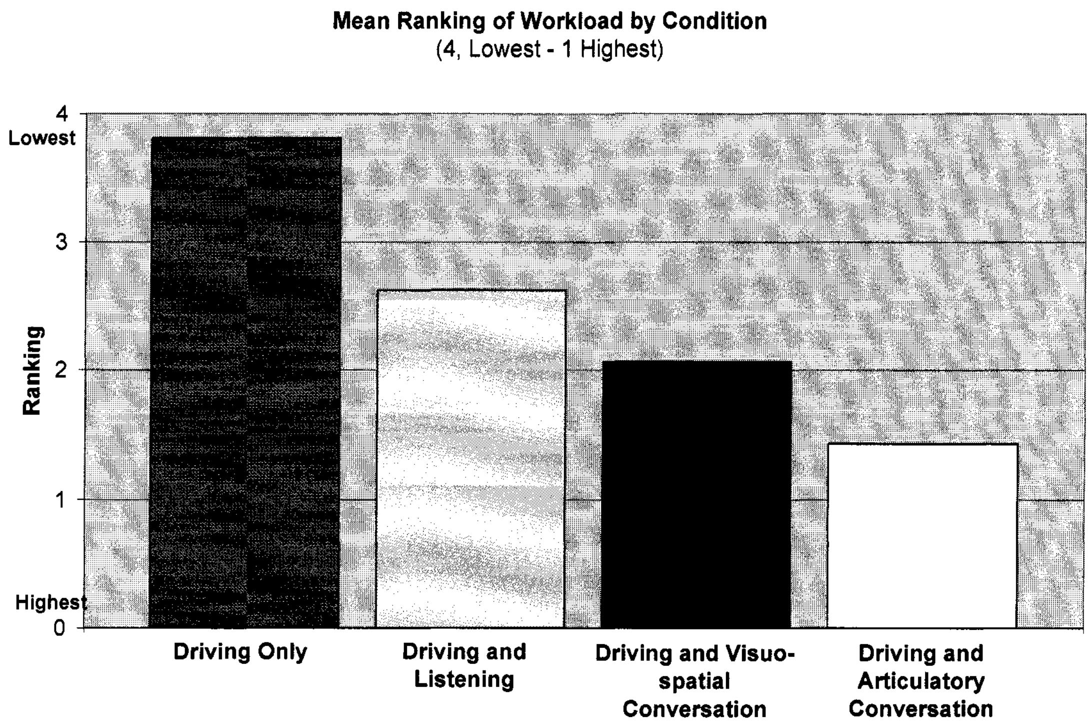

Figure 17. Mean ranking of workload by condition.

Question 5.

5.Which condition did you most prefer:
(1, liked best – 4, liked least)
_____Driving with no other activities

_____Driving and listening

_____Driving and speaking about concepts (government--social services, election issues, pollution-- world issues –the environment, poverty, nuclear proliferation, etc.— and energy – alternative fuel vehicles, nuclear and solar power)

_____Driving and speaking about places or things (describing the home you grew up in, museums, concerts, stores, and driving directions.)

The average score for preference was 1.59. Driving and listening had an average preference score of 2.13. Driving and speaking about concepts (articulatory response) had an average preference score of 3.59. Driving and speaking about places and things (visuo-spatial response) had an average score of 2.68. Participants' preference among conditions is shown in Figure 18.

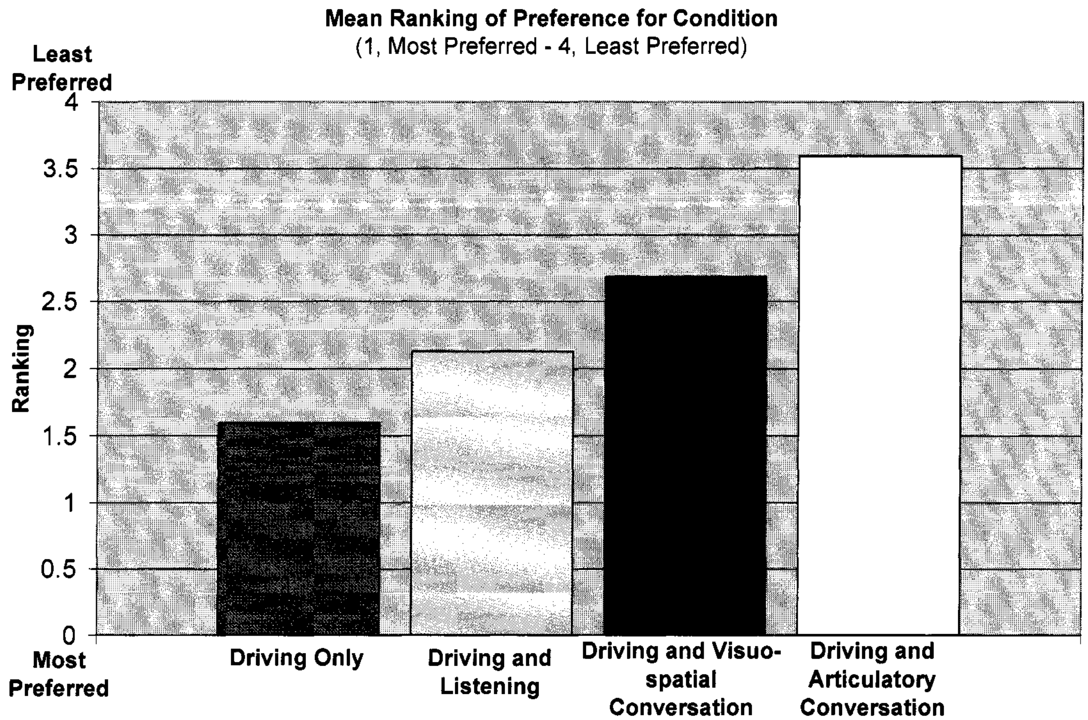

Figure 18. Mean ranking of preference for condition.

Question 6.

6. Did any of the conversations affect your driving ability? Yes Or No
If so, please describe those conversations.

Every participant that responded to this question indicated that some conversation affected their driving ability. Two participants failed to mark Yes or No. The written responses were quite varied but three specific concepts were identified by participants. The articulatory conversations were identified as affecting driving performance by 16 participants. Six participants specified a visuo-spatial conversation. Participants that indicated that both were difficult were not included in either of the aforementioned totals. The third concept identified within participant response was the idea that complexity or "depth of thought" was the determining issue for whether or not a conversation affected driving performance. Participants identified articulatory conversations, visuo-spatial conversations, and level of complexity as the characteristics of the conversations that influenced their driving performance.

Question 7.

7. What impact do you believe talking on the phone has on people's driving performance?

1	2	3	4	5	6	7	8	9	10
(improves)				(none)					(worsens)

The average score for participants' judgment of how phone conversations affect driving performance was 8.28. This indicates a strong consensus among participants that phone conversations degrade driving performance.

Question 8.

8. Please rank order the driving conditions you experienced today along the criteria listed. The condition which you believe would be the easiest to achieve the criteria should be given a rating of 1, the condition which you believe the most difficult should receive a 3.

Condition	Driving with no discussion	Driving & discussing concepts (politics, government, etc.)	Driving & discussing places & things (where you grew up places you've been, and directions)
Criteria			
Observing the speed limit			
Maintaining lane position			
Avoiding collisions			
Braking at the appropriate time and rate			

In regards to participants' ability to observe the speed limit 100% indicated the single task condition as easiest. Driving and discussing politics (articulatory response) was ranked most difficult and visuo-spatial response the middle difficulty by 69% of the participants. Only 31% of the participants considered the visuo-spatial response condition to be more difficult than the articulatory.

Driving with no discussion was indicated as the best condition for maintaining lane position by 94% of the participants. Driving and discussing places and things (visuo-spatial response) was identified as the middle difficulty by 66%. Driving and discussing concepts (articulatory response) was ranked as the most difficult condition for maintaining lane position by 69% of the sample.

Avoiding collisions was considered most easily accomplished in the single task condition by all but one participant (97%). Participants were more evenly split over which condition provided the middle difficulty with 53% indicating that driving and talking about places and things was the middle difficulty and 41% describing driving and talking about concepts as the medium condition.

Braking at the appropriate rate was considered easiest to accomplish in the driving with no discussion condition by all but one participant. Driving and talking about places and things received a score of 2 (medium) difficulty from 63% of the sample while driving and discussing concepts scored a most difficult from 66% of the participants. These rankings are depicted graphically in Figure 19.

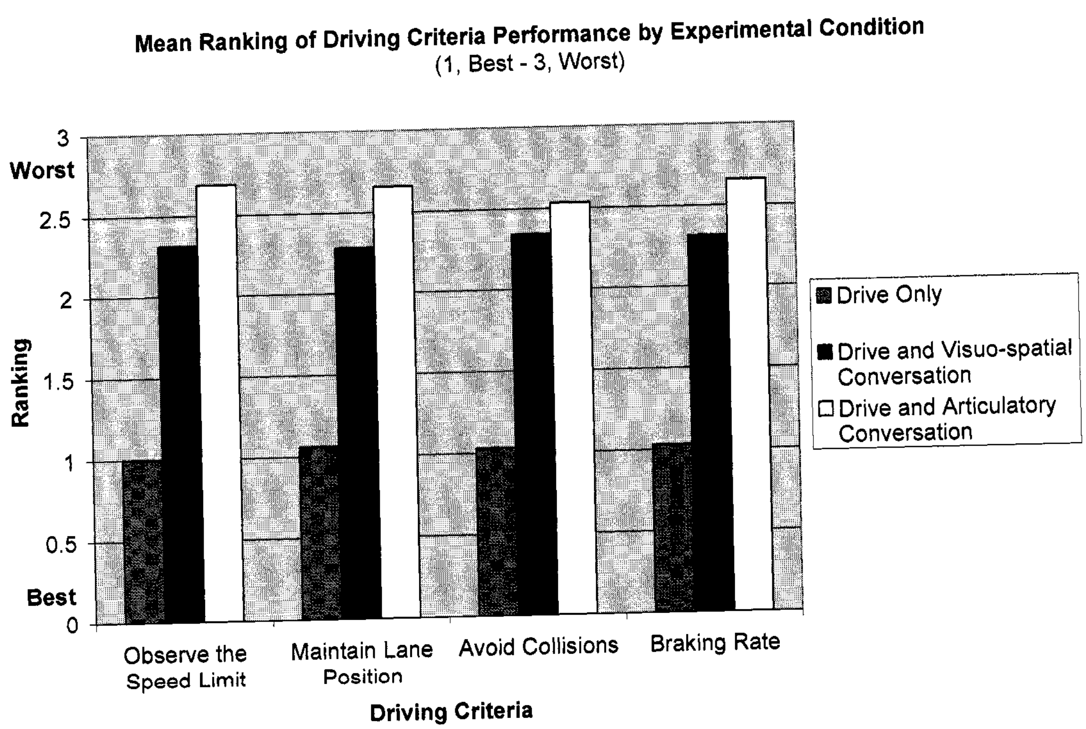

Figure 19. Mean ranking of driving criteria performance by experimental condition.

DISCUSSION

The many significant effects and interactions must be evaluated in light of the hypotheses to be evaluated in this experiment.

Hypothesis: Dual Task Worse Than Single Task

The first hypothesis based on Wickens' multiple resource theory and Baddeley's working memory model predicted that the both dual task conditions would significantly impact participants' performance of the driving task. The results of participant performance on normalized frequency of lane deviations, normalized duration of lane deviations, normalized frequency of collisions, and normalized frequency of failure to obey signal did not support this hypothesis. However, none of these measures contradicted the hypothesis that driving performance would suffer in the dual task condition since single task performance was not below that in either of the conversation conditions.

The hypothesis was supported by the participants' performance on the normalized frequency of braking control errors, normalized frequency of driving more than 5 mph above the speed limit, normalized duration of driving more than 5 mph of the speed limit, normalized frequency of driving more than 5 mph below the speed limit, and normalized duration of driving more than 5 mph below the speed limit. Participants performed significantly worse along these measures in both of the dual task conditions. This supports the assertion by both Baddeley's working memory model and multiple resource theory (Wickens, 1991) that humans have a limited processing capacity. This limitation means that when the requirements of two or more tasks exceed that processing limitation the performance of one or more of the tasks will deteriorate. Degradation of the driving task was supported in these measures of driving performance which indicates that the many processing demands of the driving and conversing tasks were more than the participants could handle. The decrease in driving performance suggests that as participants spoke on the phone they dedicated resources they needed for driving to the conversation task. As a result their driving performance suffered. These drops in performance in braking control and speed moderation could lead to safety issues in a non simulated environment. A summary of how each driving measure related to this hypothesis is contained in Table 14.

Table 14. Objective Support of Driving Measures for Single Task Versus. Dual Task Hypothesis

Driving performance measure		Single task	Driving + visuo-spatial conversation	Driving + articulatory conversation
		Mean values		
Normalized frequency of lane deviations	✔	1.7450	1.8250	1.7530
Normalized duration of lane deviations (min)		0.0307	0.0303	0.0286
Normalized frequency of collisions	✔	0.0046	0.0150	0.0460
Normalized frequency of failure to obey signal	✔	0.0090	0.0198	0.0061
Normalized frequency of braking control errors	✔	0.0452	0.1000	0.0688
Normalized frequency of driving > 5 mph above speed limit	✔	0.4269	0.8530	0.8427
Normalized duration of driving > 5 mph above speed limit (min)	✔	0.0540	0.0819	0.0864
Normalized frequency of driving > 5 mph below speed limit	✔	0.4231	1.0181	0.8303
Normalized duration of driving > 5 mph below speed limit (min)	✔	0.0690	0.1082	0.1084

(shaded) Indicates best performance for a given criteria

✔ Indicates statistically significant support for hypothesis

✔ Indicates trend support for hypothesis

The subjective data also supported this position. Subjects' assessment of the single task condition versus the dual task conditions demonstrated their belief that the dual task was more difficult. This is communicated in the results regarding driving performance under various conditions (subjective questions 2 – Figure 15, 3 – Figure 16 , and 8 – Figure 19), cognitive workload of the various conditions (subjective question 4- Figure 17), and their preference (subjective question 5 – Figure 18). Participant's ability to self assess their performance when comparing the single task condition with the dual task conditions was good and further supported the hypothesis.

This hypothesis was supported by the majority of the objective measures. Five of the nine objective driving measures demonstrated a significant decrement in driving performance during the dual task driving and speaking condition. As a result the first hypothesis is supported in the results of this study.

Hypothesis: Visuo-spatial Processing Will Interfere More With Driving Than Articulatory Processing

The second hypothesis tested in this experiment is that driving performance in the visuo-spatial conversation condition will be worse than that observed in the articulatory task condition. This effect would represent the assertion in multiple resource theory that two tasks which utilize the same resources will not be as effectively time shared as two that do not share resources (Wickens, 1991). Since driving is known to utilize visuo-spatial resources, it would be predicted that the visuo-spatial conversation would show greater decrement.

The previous hypothesis addressed the multiple resource theory assertion that two tasks that utilize resources at the same stage would interfere more than two that did not. This second hypothesis proposes an additional challenge for concurrently driving and participating in a visuo-spatial based conversation; namely a resource conflict between the two tasks that both require spatial processing resources.

The results of participant performance on normalized frequency of lane deviations, normalized duration of lane deviations, normalized frequency of collisions, normalized frequency of failure to obey signal, normalized frequency of driving more than 5 mph above the speed limit, normalized duration of driving more than 5 mph above the speed limit, and the normalized duration of driving more than 5 mph below the speed limit did not support this hypothesis. However, none of these measures contradicted the hypothesis that driving performance would suffer more in the visuo-spatial conversation condition than the articulatory conversation condition. This is represented in the data since performance of the driving task during the articulatory conversation was never below that of the visuo-spatial conversation condition.

The hypothesis was supported by the results of the normalized frequency of braking control errors and normalized frequency of driving more than 5 mph below the speed limit performance measures. Each of these driving measures revealed a significant decrease in performance in the visuo-spatial conversation condition versus the articulatory conversation condition. This finding supported the findings of Recarte and Nunes (2000) who found that the processing code of a secondary task was significant. In their study, they found the effect of a secondary spatial-imagery task while driving to have a significant impact upon eye movement. Across many measures of eye movement, the imagery task had a greater impact than did the secondary verbal task. This reduction in eye movements would be of obvious detriment to driving performance and could relate to the decrement in braking and speed moderation performance of participants in this study. A summary of the driving measure results and their support for the hypothesis can be seen in Table 15.

Table 15. Objective Support of Driving Measures for Visuo-spatial Versus Articulatory Hypothesis

		Experimental condition		
		Single task	Driving + visuo-spatial conversation	Driving + articulatory conversation
Driving performance measure		Mean values		
Normalized frequency of lane deviations	✓	1.7450	1.8250	1.7530
Normalized duration of lane deviations (min)		0.0307	0.0303	0.0286
Normalized frequency of collisions		0.0046	0.0150	0.0460
Normalized frequency of failure to obey signal	✓	0.0090	0.0198	0.0061
Normalized frequency of braking control errors	✓	0.0452	0.1000	0.0688
Normalized frequency of driving > 5 mph above speed limit	✓	0.4269	0.8530	0.8427
Normalized duration of driving > 5 mph above speed limit(min)		0.0540	0.0819	0.0864
Normalized frequency of driving > 5 mph below speed limit	✓	0.4231	1.0181	0.8303
Normalized duration of driving > 5 mph below speed limit(min)		0.0690	0.1082	0.1084

Indicates best performance for a given criteria

✓ Indicates statistically significant support for hypothesis

✓ Indicates trend support for hypothesis

The results of the subjective data did not support the hypothesis and contradicted the objective measures. Subjects' assessment of the visuo-spatial condition versus the articulatory conditions demonstrated their belief that the articulatory condition produced more interference with the driving task. This is demonstrated in the results regarding driving performance under various conditions (subjective question 3 - Figure 16 and 8 - Figure 19) where participants indicated their belief that their driving performance was worse during the articulatory conversation than during the visuo-spatial conversation. Particpants' assessment of cognitive workload of the various conditions (subjective question 4 - Figure 17) would also predict worse driving in the articulatory condition but was not observed. Finally Participants expressed their preference (subjective question 5 - Figure 18) for driving in the visuo-spatial conversation condition to the articulatory conversation.

The contradiction of the subjective and objective data was not too surprising. Individuals often fail to properly assess their performance and are instead influenced by superficial factors. As it pertains to this study participants may have been more sensitive to the perceived difference in complexity, which many cited in their response to subjective question 6 (see pages 61-62), than they were to actual changes in their driving performance. This tendency is described by Andre and Wickens (1995) in their article "When Users Want What's Not Best For Them.". The limitations of self-assessment are why objective data is inherently more reliable. This discrepancy in objective measures and subjective perception underscores the need for this study and the responsibility of researchers to inform the public and should not be considered to suggest that this hypothesis is without merit.

Another important aspect is the automaticity of the driving task. Automobile operation can become a highly practiced task. Multiple resource theory acknowledges that tasks which are highly practiced require fewer resources than those which are not (Wickens & Hollands, 2000). As a result multiple resource theory predicts that a highly practiced task will be shared more effective with other activities than a task that is not highly practiced. The amount of practice which many drivers have may be an additional cause for the limited difference observed between the two types of conversation.

The results do not conclusively support the hypothesis that visuo-spatial conversations would cause greater decrements in driving performance than would articulatory conversations. Only two of the nine objective driving measures provided significant support for the hypothesis. However, the trend support apparent in three other objective measures suggests that the hypothesis warrants further investigation.

Gender Effects

Several effects and interactions where observed among the results which did not relate directly to either of the proposed hypotheses. Two main effects were related to gender. Female participants were found to have significantly more lane deviations than did males. Females were also found to be significantly more likely to have a collision than were males. This finding could relate to the research of Lesch and Hancock (2003). Their work suggested that women did not adopt strategies to compensate for degraded driving performance while talking on a mobile phone. If that were true among this sample it could explain the higher rate of lane deviations and collisions. The mean performance by gender for each criterion is contained in Table 16.

Table 16. Mean Performance by Gender for Driving Criteria

		Gender	
		Male	Female
Driving performance measure		Mean values	
Normalized frequency of lane deviations	✔	1.260	2.288
Normalized duration of lane deviations (min)		0.028	0.031
Normalized frequency of collisions	✔	0.001	0.010
Normalized frequency of failure to obey signal		0.011	0.012
Normalized frequency of braking control errors		0.066	0.077
Normalized frequency of driving > 5 mph above speed limit		0.666	0.749
Normalized duration of driving > 5 mph above speed limit (min)		0.079	0.069
Normalized frequency of driving > 5 mph below speed limit		0.749	0.607
Normalized duration of driving > 5 mph below speed limit (min)		0.103	0.088

(shaded) Indicates best performance for a given criteria

✔ Indicates statistically significant superior performance

Experience Effects

Experienced drivers showed longer duration lane deviations in the visuo-spatial response condition while novice drivers improved their performance (see Figure 7), relative to single task performance. Experience also interacted significantly with processing code for the frequency of driving more than 5 mph below the speed limit (see Figure 13). Experienced drivers drove below the speed limit more frequently during the two dual task conditions than did novice drivers. This could be considered to support the legislation proposed to forbid the use of mobile phones among young drivers (Rau, 2004) if one believes driving below the speed limit while talking on a mobile phone is safer than driving at the speed limit while on a mobile phone. This position would suggest that experienced drivers slow down to compensate for the decrease in driving performance that might result from them speaking on the phone concurrently with driving. Alternatively, it might be considered proof that novice drivers are better able to moderate their speed while using a mobile phone than can experienced drivers. This superior speed moderation could be explained by greater sensitivity to speed among novice drivers while more experienced drivers might be more complacent.

These interactions do not support the validity of proposed restrictions on newer drivers. As a result of these findings experience does not seem to play a significant role in moderating the effects of mobile phone conversation on driving performance. The mean performance by experience for each criterion is contained in Table 17.

Table 17. Mean Performance by Experience for Driving Criteria

	Experience	
	Novice	Experienced
Driving performance measure	Mean values	
Normalized frequency of lane deviations	1.716	1.832
Normalized duration of lane deviations (min) ✓	0.026	0.034
Normalized frequency of collisions	0.005	0.006
Normalized frequency of failure to obey signal	0.012	0.011
Normalized frequency of braking control errors	0.059	0.084
Normalized frequency of driving > 5 mph above speed limit	0.769	0.646
Normalized duration of driving > 5 mph above speed limit (min)	0.069	0.079
Normalized frequency of driving > 5 mph below speed limit ✓	0.595	0.761
Normalized duration of driving > 5 mph below speed limit (min)	0.087	0.103

Indicates best performance for a given criteria

✓ Indicates statistically significant superior performance

Implications

The results of this study supported the existing body of research which indicates that driving while conversing on a mobile phone causes decreased driving performance. The simulation of hands free mobile set use while driving revealed a drop in driving performance for 5 of the nine measures evaluated. This suggests that the drivers should be discouraged from driving and using mobile phones even when they have the aid of a hands free device. This advice matches with participant responses which on the average indicated a belief that talking on a mobile device while driving worsened driving performance.

Furthermore, the difference in driving performance between the articulatory and visuo-spatial conditions provides additional information about driving safety. Little has been communicated to the general public regarding the potential impact of the content of a conversation upon driving performance. It seems reasonable that the public should be admonished from discussing things which require visualization while they drive. This is particularly poignant since the majority of participants believed that the articulatory condition produced worse driving performance when in fact it was the visuo-spatial conversation that caused the greater decrement.

LIMITATIONS

Variability in Design

Traditional basic research has, by nature, been reductionist. In order to examine a particular phenomenon or mechanism, experimental conditions were reduced in complexity in order to eliminate variability outside of the very specific element under study. It was crucial that the mechanism be isolated in order to uncover its characteristics and functionality.

This investigation was not aimed at describing a particular phenomenon. Rather it was an effort to gain insight as to how a defined mechanism, processing codes within multiple resource theory, influenced performance within a complex environment. The design of this study was less controlled than some might consider optimal. Each participant encountered different driving events and they might have taken different routes. The design's emphasis on naturalistic conversation, in itself, introduced variability as each participant was free to elaborate and respond to the experimenter in a free format. The participants' replies were not constrained to mathematical problem solving, but could be descriptive and elaborate, hopefully much like real-life.

While this did introduce uncertainty, it also improved applicability. The danger of the reductionist approach to experimental design is that it may not be applicable outside of the tightly constrained laboratory environment in which it is studied. As a result, the findings of such basic research can be limited in usefulness.

This is not a particularly new issue. Rouse (1985) discussed the challenge of bridging the gap between academic basic research and practitioners' application nearly

20 years ago. More recently Vicente (1997) considered the challenge in great detail. He proposed that there were in fact four general types of research, ranging from Type 1, highly controlled laboratory experiments (basic research) to Type 4 research, which he defined as qualitative and lacking in experimental control. Vicente proposed that all 4 varieties of research were valuable at different stages of the investigative process and that, when used together, could fully and effectively explore an issue.

Vicente described the usefulness of Type 3 research as experiments conducted in simulators that could be used "...to determine whether results obtained under research Types 1 and 2 prevailed in the face of myriad additional factors..." (Vicente, 1997, p.326). This was precisely the aim of this study. The design was intended to evaluate the use of multiple resource theory, in particular the concept of multiple processing codes, to predict task interference and performance degradation within the dual task driving and phone use environment. While it did not bear the tight control of variables associated with basic research, it did strive to test the application of the results.

General Limitations

Several specific aspects of this study introduced the possibility of errors and limited the generalization of the results to the actual driving environment. Perhaps one of the foremost limitations was the fidelity of the driving simulation used. More advanced simulators use multiple screens or projections on to even larger areas of display to provide a more engrossing experience. Advanced driving simulators often utilize actual automobile interiors as the driving environment, while this study used a desk mounted steering wheel and a pedal set placed on the floor.

The simulation system also lacked data collection capabilities. As a result, it required a process of reviewing each experimental session and transcribing the observed events. This certainly introduced the possibility of error on the part of the data transcriber with events being missed or misjudged.

While the total participant number of 32 was a reasonable start for determining statistical significance for the population as a whole, the sub groups of gender and experience numbered only 16 that was arguably too small a sample to bear much power. Further stratification of the sample by both gender and experience reduced the power further, as each of those groups contained only 8 members.

Research by Melissa Sleeter (2004) has suggested that differences in complexity can have a significant impact upon driving performance. The complexity of the two conversation scripts was not controlled. The levels of complexity of the scripts were not specifically controlled nor were they compared with any objective measure. As a result the difference in performance between the two conversation conditions may have been influenced by this difference. It is important to note that the feedback from the subjective surveys indicates that participants found the articulatory script more difficult than the visuo-spatial which implies that the difference between conditions may have been even more strongly supported had the scripts been of equal complexity.

FUTURE RESEARCH

The results of this study raised several questions for future research. How would the use of a more high fidelity driving simulator impact the result of this investigation? Repeating this study in an advanced simulator with motion capability and in general more fidelity would help to answer what, if any, impact the limitations of the equipment had on the accuracy of the findings. Furthermore, if the experiment were duplicated with equipment that performed data collection within the simulation, it would eliminate any errors that were introduced in the current study by the data transcription process.

Driver distraction is an important issue as more and more technology becomes mobile and integrated into individuals' everyday lives. While recent research has indicated that driving and mobile phone use is a cause for concern, some have argued that there are many other distractions that effect drivers and that phone use shouldn't be singled out for restriction. It would be interesting to test this idea by conducting a study that evaluated the impact of a variety of different distraction types including: mobile phone use, conversing with a passenger, drinking, tuning the radio, and coping with an unruly child to name a few. Such a study would help drivers understand what poses the greatest impairment to the driving performance and would direct researchers and designers to those distractions that warrant the most attention.

Additionally, the study could be repeated with more control for the complexity, or difficulty, of the two conversation conditions. The observation of the experimenter and the subjective surveys demonstrated that participants found the articulatory script to more difficult. This suggests that the differences between the driving performances observed during the different conversations might have been greater if complexity had been better controlled. With that in mind a repeat of the experiment with visuo-spatial and articulatory conversations of equal complexity might further strengthen the objective support for the application of multiple resource theory to the driving environment. Therefore, the experiment should be repeated with two conversation scripts which produced levels of cognitive demand which were demonstrated to be equivalent.

CONCLUSION

The results of this study support the traditional assertion that driving and using a mobile phone significantly degrades driving performance in many ways. Additionally, the findings of this experiment provide limited support for the application of multiple resource theory to predicting how the processing demands of a conversation might further affect driving performance. This theory, coupled with the results of the present study, suggests that drivers should be cautious of conversations that require visuo-spatial processing resources. The greatest effect observed was that driving performance was significantly worse in the dual task condition of driving and hands free mobile phone use than in the single task condition of driving alone.

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Appendix A Phone Screener

Name: ___________________________________

Phone: _______________work _______________ home ___________mobile

Email: _______________________ Preferred Contact Method: _____________

Demographic Information:

Gender: ___________

What is your age? _____

If under 18 "Thank you for your interest but we are looking for drivers 18 and up."

Do you have a current driver's license from the U.S.? ____ Yes ____No

IF No say: "Thank you for your interest, but we're focusing on licensed drivers for this study. Thank you for your time."

How many years have you been a licensed driver? ____ 0-2 ____ 3-9 _____10+

IF 3-9 say: "Thank you for your interest, but we're focusing on licensed drivers with a different level of experience for this study."

Do you own a mobile or cell phone? ___Yes ____No > Have you ever used it while driving? ____Yes ___No

If No say:" Thank you for your interest, but we are focusing on individual's who have used mobile phones while driving.

How frequently do you drive and use your mobile phone? (check one)

Once a month or less___ several times a month___ once a week____
several times per week___ once a day ____ several times per day___

Can you present a photo ID with your birth date? _____Yes ____No

If No say:" Thank you for your interest but the study requires verification of age.

Conclusion:
"Thank you for your time. You fit the profile of people we are looking for at this time. Let me provide you with the details about the schedule and location, and then we can schedule your session."

How many moving violations have you been cited for in the last three years?

0___ 1____ 2____ 3____ 4 or more____

Schedule then "I will email you a confirmation of the time and date that will include directions to the lab where we will conduct the study."

Appendix B Participant Instructions

The purpose of this research is to improve our understanding of how mobile phone use affects driving performance. In a moment we will review the driving simulator. You will be given some time to familiarize yourself with the environment and the controls of the simulator. Your goal is to navigate through the virtual driving environment while conversing with the experimenter as though we were friends having a casual conversation over a mobile phone. You may or may not be familiar with a topic but do your best to supply an answer. During the simulation you are to observe all "rules of the road" such as speed limits, following distances, right of way, stopping at red lights and stop signs, staying in your lane, and avoiding collisions. to the best of your ability. Your goal is to do your best to drive safely first and foremost and secondly to actively participate in the conversation. With that in mind please engage in the conversation as much as is possible.

Please take whatever time necessary to review this consent form. [present consent form and check ID]. When you are done I will answer any questions you may have. If you agree to the conditions specified please sign the form so we can proceed.

If at any time during the session you need to take a break for any reason please let me know and I will be happy to pause the simulation. Do you have any questions before we begin? Please turn off your cell phone or pager so the session won't be interrupted.

Appendix C Driving Simulator Instructions

To be read by experimenter

These controls and computer screen are the driving simulator. The wheel in front of you operates like a steering wheel and will provide some feedback as you drive. The paddles just behind the wheel on each side allow you to look to the left and right respectively. The foot pedals on the floor beneath the desk are the brake and accelerator. The screen displays your view from inside the car. The rearview mirror is visible and will show traffic behind you during the simulation. Also note the speedometer that indicates your rate of travel since observing the speed limit is a big part of safe driving.

Driving a simulator can be more difficult than driving a real car. However, it is important that you do your best and that driving safely is given priority. Maintaining proper lane position, obeying the speed limit, stopping at red lights and stop signs, and avoiding other vehicles are all very important.

In the lower right corner of the screen you see a "birds eye view" map. Your location and direction is noted by the triangle. During the simulation you will drive through a representation of Chicago. You will drive a route known as the loop that travels around the cit and involves both surface street driving and freeway driving. **[Show map with highlighted Loop Route]**. The map is also located to the left of the screen for reference if you ever need it. The speed limit on surface streets is 35 mph and the freeway speed limit is 65 mph. Take a right toward the lake on the map and then proceed north staying to the right as you continue around the city.

If at any time you are stopped and must reverse to drive around someone just let me know by speaking aloud and I will operate the transmission for you as necessary. If you are involved in an accident I will reset the simulation to restore your vehicle and we will continue from the start.

At various times within the simulation you will hear a phone ring (play ring as example). You need to answer the phone by saying "hello" and the conversation will begin. At the end of each conversation simply say goodbye to hang-up.

Remember that at any point you need to take a break or have a question just say so. Do you have any questions? For the next five minutes you can familiarize yourself with the driving in the simulator before we begin.

Appendix D Map of Simulated Chicago

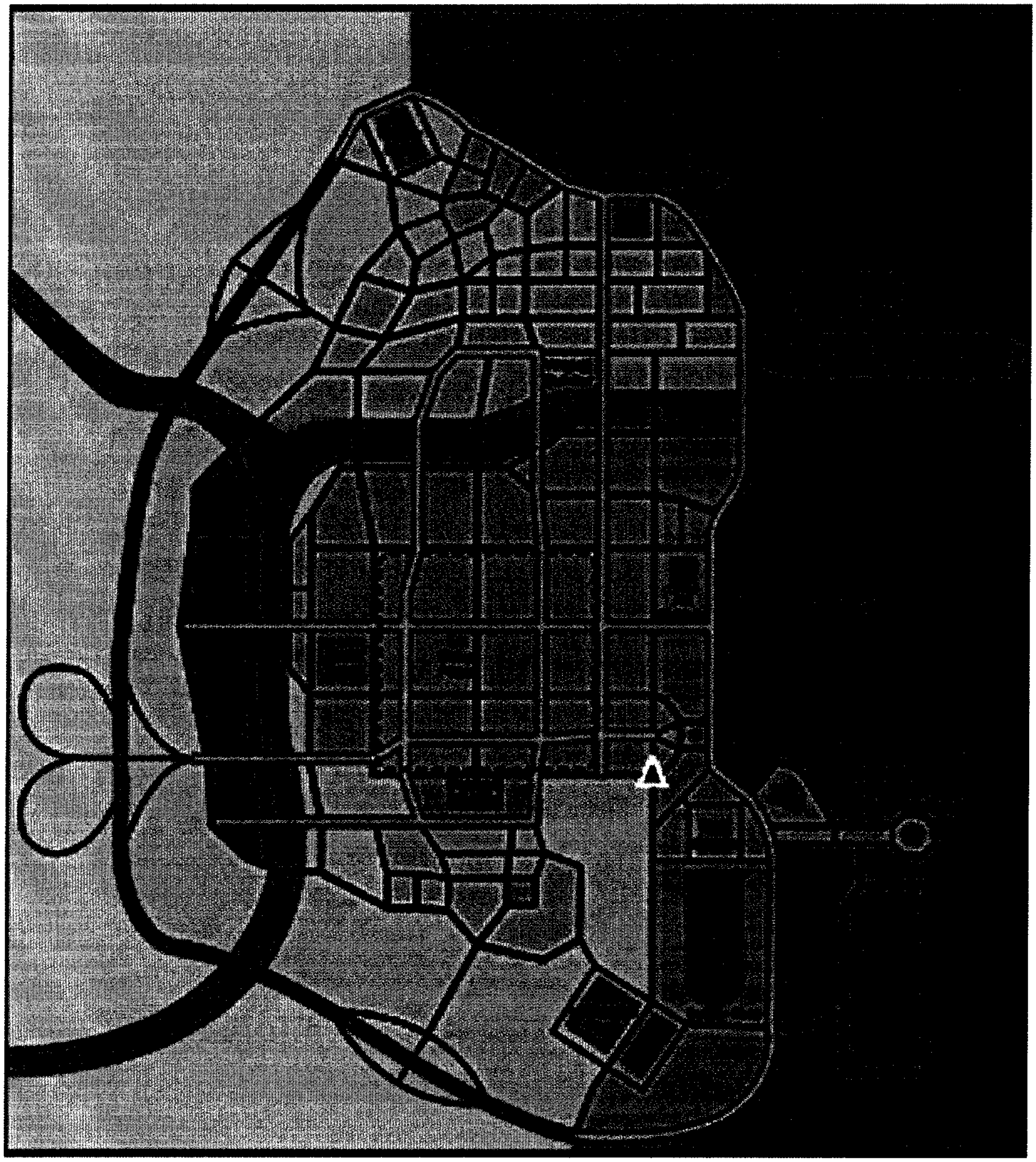

Figure 20. Map of simulated Chicago including "Loop" route.

Appendix E Participant Activity Outline

<table>
<tr><th>Minutes</th><th colspan="2">Activity</th></tr>
<tr><td>15</td><td colspan="2">Greeting, consent form, demographic survey, and instructions</td></tr>
<tr><td>5</td><td colspan="2">Familiarization with simulator</td></tr>
<tr><td rowspan="9">60</td><td>Task Schedule even participants</td><td>Task Schedule odd participants</td></tr>
<tr><td>5 minutes single task</td><td>5 minutes single task</td></tr>
<tr><td>10 minutes dual task - Verbal</td><td>10 minutes dual task - Spatial</td></tr>
<tr><td>5 minutes single task</td><td>5 minutes single task</td></tr>
<tr><td>10 minutes dual task - Spatial</td><td>10 minutes dual task - Verbal</td></tr>
<tr><td>5 minutes single task</td><td>5 minutes single task</td></tr>
<tr><td>10 minutes dual task - Verbal</td><td>10 minutes dual task - Spatial</td></tr>
<tr><td>5 minutes single task</td><td>5 minutes single task</td></tr>
<tr><td>10 minutes dual task - Spatial</td><td>10 minutes dual task - Verbal</td></tr>
<tr><td>10</td><td colspan="2">Survey and participant debriefing</td></tr>
<tr><td>Total</td><td colspan="2"></td></tr>
<tr><td>90 min.</td><td colspan="2">Total estimated session time</td></tr>
</table>

Appendix F Post-Participation Questionnaire

________Participant No.

1. Please rate how accurately the driving simulator modeled actual driving:
(1, very poorly - 10, very well)

______

2. Please rank your driving performance during the following conditions:
(1, best - 3, worst)

______Driving with no other activities

______Driving and listening

______Driving and speaking

3. Please rank your driving performance during the following conditions:
(1,best - 3,worst)

______Driving with no other activities

______Driving and discussing concepts (government--social services, election issues, pollution-- world issues –the environment, poverty, nuclear proliferation, etc.—and energy – alternative fuel vehicles, nuclear and solar power)

______Driving and discussing things and places (describing the home you grew up in, museums, concerts, stores, and driving directions.)

________Participant No.

Workload relates to how much of your total mental capacity is being used.

4.Please rank the following conditions as they relate to the amount of workload you experienced during today's simulation:
(1 highest workload – 4 lowest workload)

_____Driving with no other activities

_____Driving and listening

_____Driving and speaking about concepts (government--social services, election issues, pollution-- world issues –the environment, poverty, nuclear proliferation, etc.— and energy – alternative fuel vehicles, nuclear and solar power)

_____Driving and speaking about places or things (describing the home you grew up in, museums, concerts, stores, and driving directions.)

5.Which condition did you most prefer:
(1, liked best – 4 liked least)
_____Driving with no other activities

_____Driving and listening

_____ Driving and speaking about concepts (government--social services, election issues, pollution-- world issues –the environment, poverty, nuclear proliferation, etc.— and energy – alternative fuel vehicles, nuclear and solar power)

_____ Driving and speaking about places or things (describing the home you grew up in, museums, concerts, stores, and driving directions.)

________Participant No.

6. Did any of the conversations affect your driving ability? Yes Or No
If so, please describe those conversations.

____

____

____

____

____

____

7. What impact do you believe talking on the phone has on people's driving performance?

1	2	3	4	5	6	7	8	9	10
(improves)				(none)					(worsens)

________Participant No.

8. Please rank order the driving conditions you experienced today along the criteria listed. The condition which you believe would be the easiest to achieve the criteria should be given a rating of 1, the condition which you believe the most difficult should receive a 3.

Condition	Driving with no discussion	Driving & discussing concepts (politics, government, etc.)	Driving & discussing places & things (where you grew up places you've been, and directions)
Criteria			
Observing the speed limit			
Maintaining lane position			
Avoiding collisions			
Braking at the appropriate time and rate			

Appendix G Conversation Script: Visuo-Spatial Coding

Topic: The home you grew up in

General	Where was the home you grew up in located?
Exterior	What did your house look like from the outside?
Exterior	Did you have a big yard? What kind of landscaping was there? (Garden trees pool)
Exterior	Were there shutters around the windows?
Interior	Starting from just inside the front door walk me through the house.
Kitchen	How was the kitchen configured?
Kitchen	What kind of floor did it have? If tile describe?
Bath	How do you get to the bathroom from the kitchen?
Bath	Were the walls painted or did they have wallpaper? describe
Bedrm	Describe your bedroom? Prompt re: furniture, wall color, posters/pictures
Bedrm	How big was your room? Do you remember how many electrical outlets there were? Where were they located?
Bedrm	Where were the windows located? What would you see when you looked out the window?

Topic: Places you have visited

Museum	Have you ever been to a museum?
	What was the last museum you went to? (If local how do you get there?)
	What did it look like from the outside?
	What was your favorite exhibit? What did it contain?
	What was the most interesting piece in the exhibit? Please describe it.
	Could you tell me how to get to that exhibit from the entrance?
Concert	Have you ever been to a concert/public performance?
	Where was the last concert you went to?
	Can you describe the venue?
	Where were your seats located?
	Where do you think the best seats were?
Alcatraz	Have you ever visited Alcatraz?
	What do the cells look like?
	Describe your most vivid memory of Alcatraz.

Topic: Navigation

The lab	Please describe turn by turn how you drove to the lab today.
Work	What place outside of your home do you drive to most frequently? Can you give me directions on how to get there from your home?
Pac-bell	Do you know where Pac-bell park is? How would I get there from here?
Golden Gate	I really want to go to the Golden Gate bridge tonight. Can you tell me how to get there from here?
Monterey Bay Aquarium	Can you tell me how to drive from here to the Monterey Bay Aquarium

Topic: Describe

Outdoors	How would you describe a redwood tree to someone who has never seen one?
	If that person wanted to see one in person could you give them directions to somewhere you know there are redwoods? What would those directions be?
	Describe any outdoor activities you participate in. Where, what, how do you do it?
	Please describe any national monuments you have visited.

Appendix H Conversation Script: Auditory Articulatory Coding

Topic: Government

Soc. serv	Do you think the government should provide social services?
	Why or Why not?
	What is the most (least) important service offered? Why?
Taxes	What do you think of the current tax structure in the US?
	Are you familiar with the idea of a flat tax rate? If yes what do you think are its strengths or its weaknesses?
	If no one was required to pay taxes how would that affect life as we know it in the US?
Elections	Campaigning in the US is largely effected by a candidate's ability to raise funds. Some think companies' contributions to certain officials gives them influence within the government. What do you thin would be the impact of forbidding company contributions to political campaigns
Electr. vt	Do you think that the US should use electronic voting machines at all of the poles? Why?
	Do you think using the old system might lead to similar problems this year?
Pollution	The EPA has recently announced that it wants to reduce policing of company emissions. The proposal is to allow companies to self-regulate. Why do or don't you think this is a good idea?
President	Who was you favorite president and why?
Arnold	How do you think Arnold Schwarzenegger is doing as Governor and Why?
Space	So you believe that Americas continued efforts in space are important? Why or Why not?

Topic: World issues

Enviro	Do you think global warming is a serious issue? Why/ why not?
	Considering that deforestation is primarily a problem in second and third world countries? What if anything should 1st world countries do about this? If not who should do what and how?
	2/3 of the earth is water but non nation has jurisdiction over most of the oceans on the planet. How should these waters be protected from pollution?
Poverty	Do you think the level of poverty around the world has far reaching effects? Why/why not?
	How do you think poverty might be related to terrorism?
Nuclear prolif	Do you think that the development of nuclear weapons should be restricted? Why not or who should monitor this and how?
AIDS	The spread of AIDS is a continually growing problem in Africa. Do you have any suggestions of what could be done to help with this problem?
Media	What ways do you think the media influences the perception of world events?
Media	How can individuals overcome this influence?
UN	Do you think the UN is an effective international organization? Why or Why

	not and can you give an example that demonstrates your perspective?

Topic: Energy

Alt-Fuel	Do you know anyone with a hybrid or alternative fuel car? If yes what do you think of it?
Alt-Fuel	Should the development of alternative fuel vehicles by actively encouraged by the government or should it be driven by market demand? Why?
Nuclear	What do you think are the strengths and weaknesses of nuclear reactors as a power source?
	How do you expect nuclear power to be used in the future or what do you expect to replace it?
Solar	Do you know anyone who uses solar power at their home or work?
	What do you think of solar power as an energy source?
	Various incentives are being considered for people and companies who utilize solar power. Is this a good idea? Why/why not?

Topic: Business

Starbucks	Have you ever gone to Starbucks? If yes as you probably know it is a very successful business. Why do you think that is?
Starbucks	Some people say that Starbucks is pushing out small private businesses? Do you think that they compete fairly? Follow up to response.
Fast-Legal	Did you hear about the lawsuit brought against McDonalds by individuals who blamed the restaurant chain for a variety of health problems? What do you think about the legitimacy of their suit?